EPA-COUNCIL-11-xxx

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: Review of the Draft Report to Congress on Black Carbon

Dear Administrator Jackson:

Black carbon is a mixture of light-absorbing particles that results from incomplete combustion of organic materials such as petroleum fuels or biomass, and these particles have been implicated in climate change and impacts on human health. In 2009, Congress directed the EPA, in consultation with other federal agencies, to summarize the available science on the impacts of black carbon on climate, sources of black carbon emissions, benefits to climate and human health from reductions in those emissions, and the cost-effectiveness of available mitigation strategies. The EPA requested the Advisory Council on Clean Air Compliance Analysis to review the draft EPA document, *Report to Congress on Black Carbon,* with respect to its accuracy and clarity in summarizing the available scientific literature, including uncertainties. The Council, augmented with experts in the chemistry, modeling and control of black carbon, has reviewed the draft EPA report and provides advice and recommendations in the enclosed report.

The Council commends the Agency on the quality of the draft report. It is comprehensive and well-written, and summarizes much of the relevant scientific literature on the nature of black carbon particles; their formation, transformation and transport in the atmosphere; associated climate and health impacts; and possible mitigation technologies. In addition, the Report successfully uses text boxes and figures to convey a wealth of complex information. However, the enclosed Council report has many substantial recommendations for how the EPA report can be improved.

The preponderance of the available data support a conclusion that there are actions to reduce black carbon emissions that will be a “win-win” for public health and climate, and the Council urges the Agency to strengthen this message in the report. The report should expand the discussion of health effects associated with black carbon, which is a component of particulate matter, and highlight the considerable health benefits that would derive from reductions in black carbon emissions.

In addition, the Council recommends that the report be revised to include a more rigorous treatment of benefits and costs and associated uncertainties of black carbon mitigation options to inform policy. Without prescribing specific policies, the report should develop recommendations for black carbon mitigation strategies in the short-term, longer term, and for rapidly industrializing countries, and discuss how the selection of metrics and mitigation approaches would differ for the three objectives.

The EPA report appropriately emphasizes that black carbon reductions should not be viewed as a substitute for needed reductions in long-lived greenhouse gases (including carbon dioxide and methane) over the long term, but is relatively silent on the unique benefits that might be expected from changes in more near-term influences. The Council recommends a more thorough discussion of these implications and the desirability of placing a higher priority on the control of a short-term climate forcer such as black carbon than on long-lived greenhouse gases alone.

In closing, the Council agrees that meaningful reductions in short-term climate forcers such as black carbon could have profound effects on the opportunities for society to implement climate change adaptation as well as to transition to low-carbon economies. We appreciate the opportunity to provide advice and recommendations on this important topic, and look forward to your response.

Sincerely,

Dr. C. Arden Pope, III
Chair
Advisory Council on Clean Air
Compliance Analysis

Enclosure

NOTICE

This report has been written as part of the activities of the EPA Advisory Council on Clean Air Compliance Analysis (the Council), a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Council is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names of commercial products constitute a recommendation for use. Reports of the Council are posted on the EPA Web site at http://www.epa.gov/advisorycouncilcaa.

U.S. Environmental Protection Agency
Advisory Council on Clean Air Compliance Analysis
Augmented for Review of Black Carbon

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1. EXECUTIVE SUMMARY

At EPA's request, the Advisory Council on Clean Air Compliance Analysis, augmented with invited experts on black carbon, reviewed the EPA draft document, *Report to Congress on Black Carbon* (the Report). The Report was prepared in response to a Congressional request, and is intended to describe available inventories of black carbon (BC) emissions, an assessment of impacts of BC on global and regional climate, potential metrics to quantify the effects of BC and compare them to effects from other greenhouse gases (GHG), identify cost-effective BC control options, and assess the climate and public health benefits that might be achieved. The Council commends the Agency on the quality of the draft Report. The Report is comprehensive and well-written, and summarizes much of the relevant scientific literature on the nature of black carbon (BC) particles; their formation, transformation and transport in the atmosphere; associated climate and health impacts; and possible mitigation technologies. In addition, the Report successfully uses text boxes and figures to convey a wealth of complex information.

The Council recommends targeted expansion of the Report in key areas, increased attention to the use of figures and definition of terms, and incorporation of additional relevant literature. The Council offers the following priority recommendations for revisions to the draft Report:

- Based on the preponderance of available data, the Council suggests an affirmative statement that BC appears to warm climate and that BC mitigation will produce both health and climate benefits.

- The Report should expand the discussion of health effects associated with BC, drawing upon the particulate matter, traffic emissions and other relevant literature, and highlight the considerable health benefits that would derive from reductions in BC emissions. This health co-benefit may exceed climate-mediated benefits.

- To inform policy, the Report should have an additional chapter to present a more rigorous treatment of benefits and costs, and associated uncertainties of BC mitigation. The Council recommends that a summary table be developed to present cost and expected emission reductions for each technology/policy option discussed.

- Although the Report discusses uncertainties associated with emissions estimates and associated changes in radiative forcing, it fails to communicate what the total weight of evidence suggests concerning the uncertainties associated with BC. One approach to providing an overall sense of uncertainties would be to construct a table listing the primary sources of uncertainty and providing at least a qualitative assessment of each.

- The observed long-term BC downward trends in the U.S. are an important finding that should be highlighted to show that U.S. emission reduction efforts (e.g., to attain the NAAQS for PM and other pollutants) are reducing BC levels. However, the Council cautions that trends in BC emissions in other parts of the world are rising due to increases in population and/or in the number of emitting devices.

- The discussion of BC climate impacts should focus more on measures of climate response, rather than on changes in radiative forcing, so that a broader set of impacts are considered and presented in terms that are meaningful to the generalist reader.

- The Report should discuss the need for future research on which BC mitigation strategies are most cost-effective and beneficial for public health and climate, including mitigation within and across sectors, and mitigation to reduce climate impacts in sensitive regions. In addition, the Report should note that research is needed on the effect of BC deposition on the melting of snow and ice. This is particularly relevant in areas where BC deposition may affect snow pack that influences the availability of water resources for downstream populations (e.g., California, Himalayas and Tibetan Plateau, Andes, high African mountains) as well as in the Arctic, where BC deposition may be increasing the rate of melting of sea ice and thawing of tundra.

- The Report should articulate potential benefits to pursuing a goal of reducing short-term climate change or slowing the rate of change, as a complement to the existing policy goal of limiting the long-term increase in global mean temperature. The discussion of metrics should discuss how policy goals will influence the selection of appropriate metrics.

- The Report should discuss a broader range of BC mitigation approaches, including policies that could influence demand for vehicle use generally, modal substitution, enhanced energy use efficiency, electrification using wind/water/solar, and improved engine technologies.

2. INTRODUCTION

2.1. Background

Black carbon (BC) is a mixture of light-absorbing particles that result from incomplete combustion of organic materials such as petroleum fuels or biomass. These particles have been implicated in climate change and impacts on human health. In 2009, Congress directed the EPA, in consultation with other federal agencies, to summarize the available science on the impacts of BC on climate, sources of BC emissions, benefits to climate and human health from reductions in BC emissions, and the cost-effectiveness of available mitigation strategies. The EPA requested the Council to review the draft *Report to Congress on Black Carbon* with respect to its accuracy and clarity in summarizing the available scientific literature, including uncertainties. The Council, augmented with additional experts on BC, met on April 18-19, 2011, to hear public comments and technical briefings from Agency staff and to deliberate on responses to the EPA charge questions. A follow-up public teleconference of the Council was held on June 27, 2011, to discuss the Council's draft report and to agree on revisions to be made in the final Council report.

2.2. Charge to the Council

The Charge to the Council includes questions on the overall completeness and clarity of the draft *Report to Congress on Black Carbon* (the Report), including the preliminary conclusions and key messages to Congress on the state of the science on black carbon impacts and mitigation options. In addition, questions are posed on technical aspects of each of the chapters, including effects of BC on climate, public health, and the environment; BC emissions inventories; observational data; and available mitigation options (and associated control costs and benefits) for U.S. and global emissions. Charge questions are included at the beginning of each section of the Council's report, and the full charge is included as Appendix A.

3. GENERAL COMMENTS

Charge Question 1. In the Council's view, does the draft report accurately interpret and clearly communicate the findings of the current scientific and technical literature, including important uncertainties, pertaining to black carbon (BC)? Based on this literature, what are the Council's views on the preliminary conclusions as summarized in the Executive Summary and in the key messages for each chapter?

Overall, the Report provides a well-written and comprehensive summary of much of the current literature on black carbon (BC) emissions, impacts and controls and the Council commends the Agency for the quality of the initial draft. There are three areas that deserve additional clarification and emphasis. While it is not possible to fully answer each of these questions without further research, a general discussion would help to tie together the complicated issues in the Report.

Overview of uncertainty

The Report mentions uncertainty in a number of sections. Yet, the Report could do more to present an overall sense of the uncertainty in conclusions about the net climate effects of BC, given both warming and cooling effects of BC and co-emitted particles, and the desirability of particular policy responses to BC. Sources of uncertainty include model uncertainty (i.e., the extent to which atmospheric processes are accurately included), measurement uncertainty associated with different methods and the need to translate optical reading into BC mass, uncertainty in health effects of BC as a component of the particulate matter (PM) mixture, and uncertainties associated with mitigation costs and benefits. One approach to presenting an overall sense of the uncertainties associated with BC would be to include a table with qualitative discussion of the various uncertainties, similar to tables included in the Agency's recent analysis of the benefits and costs of the Clean Air Act (U.S. EPA 2011a).

A concluding summary of the uncertainties mentioned throughout the document would be helpful. What are the areas in which uncertainties arise? To what extent are the uncertainties due to lack of research? To what extent do uncertainties affect the overall conclusions? Are the basic conclusions robust to the uncertainties? The last bullet point of the executive summary should be a theme across the entire report: namely, that BC appears to warm climate and that BC controls would produce both health and climate benefits. Further work is needed to identify the most cost-effective mitigation approaches.

Comprehensive treatment of economics of black carbon

The Report needs to make clear that the environmental and health consequences associated with BC emissions are international in scope and that the costs and benefits that result from controlling BC emissions will vary widely across regions (urban and rural; developed and developing; sensitive regions and non-sensitive regions). The Report also should note that uncertainty is introduced when using U.S.-focused valuation studies in non-U.S. settings due to several factors, including (1) a lack of applicable studies; (2) differences in valuation (for example, in "value of a statistical life" (VSL) measures or in the applicability of using "avoidable mortality" or "potential years of live lost" versus "mortality" measures); and (3) regional differences in growth patterns (for both population and energy demand).

In summary, more research would be needed to fully answer the charge to identify the most cost-effective approach to mitigation. However, the Report could identify a set of opportunities for action and identify the types of policies that would be relevant.

Specifically, the Report should clarify the following issues regarding benefits and costs of BC mitigation:

- Identify what costs/benefits are considered (i.e., first order costs/benefits of technology, market changes such as changes in consumer surplus).
- Discuss whether impacts and benefits are linear with respect to BC emissions reductions.
- Identify the timing of the benefits and costs such that they are reported in consistent units (i.e., present value to some base dollar year).
- Provide guidance on how the estimates of benefits and costs of a range of policies can be compared. For some policy options there will be more uncertainty created when using U.S. valuation studies to value impacts outside the U.S. Furthermore, some policy options may look optimal in terms of monetary benefits and costs but may be less desirable because of feasibility issues.
- Care needs to be given in using valuation studies that are predominately U.S.-focused to value non-U.S. impacts.
- Avoid using the term “cost-effective” when “technology cost” or some other term more accurately represents what is provided.

Black carbon reductions benefit climate and health, despite uncertainties

The Report should emphasis that the knowledge and technology exist to decrease BC emissions, as evidenced by the history of declining emissions in the U.S. There is room for improvement, because the warming impact of BC emitted in the U.S. continues to be large. Technologies proven in the U.S. can be templates for other nations. The preponderance of the available data support a conclusion that actions to reduce BC emissions are a “win-win” for public health and climate. For example, cleaning up diesel particulates makes sense from both a climate and health perspective. The Report should bring out research that demonstrates substantive reductions from existing technologies and note that opportunities to apply these technologies are not yet exhausted. Examples brought forward include:

- Ways to reduce BC emissions in the short term: retro-fits, improving off-road vehicles (e.g., farm equipment);
- Alternatives to reduce BC emissions in the longer term (e.g., alternatives to diesel);
- Based on experience in the U.S., there is potential for “leap-frogging” of BC control technology in non-U.S. countries;
- Internationally, the suite of options for reducing BC emissions may be broader than those the U.S. has used; and
- From a global perspective, a *variety of strategies* rather than a single strategy may be most effective.

Additional Information and Studies

Charge Question 2. Is the Council aware of any additional, policy-relevant studies that should be included in the draft report to inform the preliminary conclusions? Are there specific studies that should be given more or less emphasis?

Charge Question 16. Do the technical appendices to the draft Report contain any information that should be included in the main body of the Report?

In response to Charge Question 2, the Council has recommended additional published studies that might be added to the Report, and these references are included in the relevant sections of the Council's report. In addition, the Council recommends that additional detail from Appendix A be brought forward into the body of the Report, and details of this recommendation are discussed in the sections that follow.

4. RESPONSE TO SPECIFIC CHARGE QUESTIONS

4.1. Effects on Climate

4.1.1. Types of Carbonaceous Particles

Charge Question 3. Does the draft Report accurately identify and characterize light-absorbing carbonaceous particles, including BC and brown carbon?

The Report defines black carbon (BC) as, "the carbonaceous component of PM that absorbs all wavelengths of solar radiation, … commonly referred to as 'soot'" (pp. 2-1 and 2-5). It might be more accurate to state that "soot"—the mixture consisting mostly of organic carbon (OC) and BC resulting from incomplete combustion—is the major light-absorbing component of air pollution emissions, and that the efficiency of this absorption varies with the composition, size, and morphology of the particles. BC or elemental carbon (EC) measurements are the best indicators of soot, as these particles are directly emitted from incomplete combustion, whereas OC can derive from several sources (e.g., pollens, spores, condensed vapors, secondary aerosol). The Report might note that EPA uses indicators where there is some ambiguity concerning precise quantification of the pollutant causing adverse effects. Neil Frank put this well in his comments on the 1995 critical review (Watson et al. 1995): "EPA uses a surrogate measure, referred to as an indicator, to represent the agents of concern. In the case of PM, this indicator is PM mass concentration in a specified size fraction. In order to treat the regulated community fairly and to provide a uniform level of health protection across the nation, the indicator must be consistently defined in terms of stable, reproducible measurements." PM_{10} and $PM_{2.5}$, for example, are indicators defined by the measurement method. In the U.S., EC is also an indicator defined by the method (Chow et al. 1993; 2007; 2011) applied in EPA's urban (CSN) and non-urban (IMPROVE) air quality monitoring networks.

Given the variations among studies in what was measured, and the number of terms in use for different categories of particulate matter, the Report should provide a clear set of definitions early in the Report and a glossary of terms for generalist readers. Appendix 1, which describes the various forms and measurements of BC, EC, etc., is extremely helpful, and a brief version of this appendix could be added to the main text. Figure A1-1 is particularly useful for conveying the properties of the different carbonaceous particles, and the figure should be included in the body of the Report.

Further, the Report should clarify that, of necessity, the analyses draw upon studies that use differing definitions of BC. Text boxes could be used to highlight critical information such as other names for black carbon (e.g., page 2-6), listing the proxy measures for BC (e.g., $PM_{2.5}$), and other pollutants emitted with BC (e.g., page 2-12 lines 21-23) or description of brown carbon (page 2-7, lines 12-13). The Council suggests the following wording for a text box to provide a context for the use of the term "black carbon" in the Report:

> Carbonaceous PM consists of black carbon (BC) and organic carbon (OC). We define black carbon (BC) as carbonaceous material that absorbs light at all wavelengths. However, we use historical data labeled variously as elemental carbon (EC), carbon black, soot, light absorbing carbonaceous PM, and black smoke as surrogates of BC for our review in this report. Although these terms are not strictly equivalent, we believe the validity of our analyses and conclusions are not materially compromised by our adopting this convention. All organic carbon absorbs short ultraviolet radiation, but only a portion absorbs longer UV and short visible radiation. Organic carbon that absorbs short visible radiation often appears brown or yellow, and is commonly referred to as brown carbon (BrC). Whereas, black carbon absorbs relatively uniformly across the entire solar spectrum, brown carbon preferentially absorbs UV and short-visible radiation and absorbs more weakly per unit mass than does black carbon. The major sources of BC also emit OC (thus BrC as well). Whereas, the ratio of OC:BC from diesel exhaust is around 1:1, that from biofuel burning is often 4:1 and from biomass burning, 8:1. As such, particles from biomass burning and biofuel burning in particular may cause more light absorption due to the BrC that they emit than the BC they emit.

In the Report, the physical characterization of the BC particulate matter is relatively limited, and for the most part BC is described simply as a component of $PM_{2.5}$, with both BC and $PM_{2.5}$ expressed in units of mass concentrations. However, most BC-containing particles are substantially smaller than 1 micron diameter and BC is an important component of ultrafine particles (<100 nm). For some health, optical and absorption effects, particle surface area or particle number may be a better indicator of BC effects than mass concentration. There is also a significant BC component in (or rather on) coarse particles ($PM_{10-2.5}$ and larger), especially in urban areas where coarse-mode particles (such as from re-entrained road dust) are often "coated" with BC (and substances absorbed onto it). A color photo (Figure 1, courtesy of George Allen, NESCAUM) shows coarse PM (> 2.5 microns) from a Harvard Impactor run approximately 100 ft above street level in Boston. This coarse urban PM is black, not earth-colored, and likely results from a BC surface coating of coarse mode particles, rather than from a uniform BC composition. This emphasizes the point that composition of particle surfaces and other aspects of particle morphology have important implications for the potential health, optical and climate forcing effects of BC-containing particles.

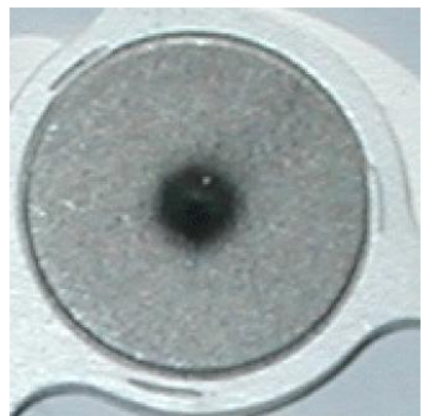

Figure 1. Coarse urban particulate matter with a black surface coating (Source: NESCAUM)

The Report should clarify that BrC may exist within the same particles as BC in soot or may exist in separate particles, and often both. Near the beginning of Chapter 2, there should be an emphasis on how the mixing state of BC can enhance its absorbing properties. Somewhere in this section, or in Appendix 1, a reference to the excellent Moosmüller et al. (2009) review of light absorption concepts and measurements should be added.

The Report correctly notes that all brown carbon (BrC) is organic carbon, with the difference being that BrC components absorb short and long UV wavelengths and short visible wavelengths, whereas the remaining organic carbon absorbs only short UV wavelengths; many chemical components in organic particles that absorb long UV and short solar wavelengths are identified in Jacobson (1999). However, the Report's discussion of BrC includes a somewhat misleading, idealized depiction of light absorption by BC and (BrC) as a function of wavelength (Figure 2-4); this figure appears to be based on the humic acid absorption plots of Andreae and Gelencser (2006) and Sun et al. (2007), or solvent extracts of emission samples (Chen and Bond 2010). The figure implies that BrC from biomass burning does not contain or absorb light like BC. However, samples taken by Chen et al. (2010) (Figures 2 and 3, below) show that even BrC can absorb strongly at longer wavelengths. Of course, it is only possible to obtain a flaming or smoldering sample in laboratory tests, as real-world ambient samples are always mixtures of emissions from the smoldering and flaming phases.

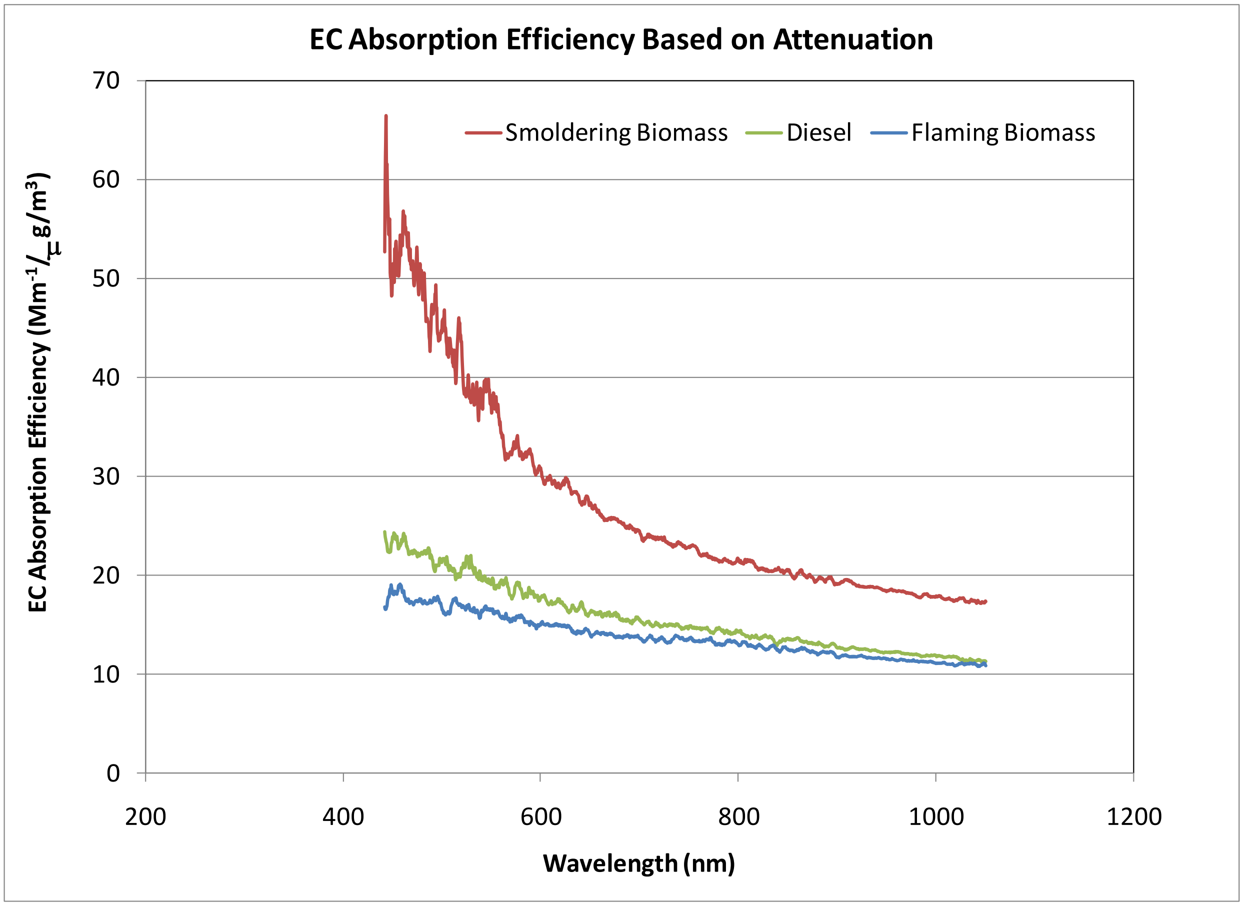

Figure 2. Absorption efficiencies as a function of wavelength for biomass smoldering, biomass flaming, and diesel exhaust (data from Chen et al. 2010). EC was measured by the IMPROVE thermal/optical reflectance method and light transmission was measured with an Oceans Optic spectrophotometer. Biomass burned consisted of moist (smoldering) and dry squaw carpet stems. Diesel exhaust was generated with an Onan Cummins diesel generator operating at 32% of full capacity (Chow et al. 2006). Filter transmittance attenuation is correlated with, but not the same as, particle absorption in the atmosphere owing to scattering within the filter and changes in particle shape after collection on the filter (Chow et al. 2010).

Figure 3. Pictures of Teflon filter samples of biomass smoldering, biomass flaming, and diesel exhaust emissions, as described in Figure 2.

Chapter 2 also notes that BC generally is expressed in mass units. However, the Council questions the practice of converting a light absorption (Mm^{-1}) measurement to BC ($\mu g/m^3$), then converting it back to absorption for radiation balance determination. It is well demonstrated in this Report and elsewhere that the mass extinction efficiency varies by particle shape, size, composition, and wavelength. There should be a stronger recommendation for reporting light absorption in the original units of absorption, or at least being more specific about the wavelengths and mass absorption efficiencies used (usually the default values programmed into an instrument by the manufacturer). Additional discussion of this issue is provided in the response to Charge Question 10 (section 4.4 below). The Council has the following additional comments:

- A table showing the radiative forcing (RF) of BC as a ratio of the mass of BC would be a helpful addition to the chapter. Comparing forcing/g for different species helps put a perspective on the role that different aerosols play both in terms of the abundance of the species and their forcing efficiency (e.g., as shown in Figure 2-9, p. 2-21). For information on the relative forcing efficiency of BC relative to other aerosols, see Schulz et al. (2006) and Menon and Del Genio (2007). Another reference that could be cited is Kopp and Mauzerall (2010), who attempt to reconcile forcings from different studies in uniform units; their presentation of effective radiative forcings for carbonaceous aerosols from combustion and biomass sources from four studies may be a useful addition to the Report.
- The suggestion (p. 2-8, line 12) that carbonaceous particles might be considered along a continuum from light-absorbing to light-scattering is quite important and should be included in the conclusions or overview as well.
- The discussion of physical transformations within emission plumes (p. 2-14) would benefit from some quantitative estimates of the change in light absorption associated with these transformations. Fuller et al. (1999) and Andreae and Gelencser (2006) provide important insights into what happens as particles age (i.e., grow in size, collapse, and absorb other materials).The extent to which these transformations are included likely explains the discrepancy between results from different models and thus it is useful to look at the range that exists currently. Additional references are available for mass absorption efficiencies of BC/EC (Horvath 1993; Dillner et al. 2001; Alfaro et al. 2004; Chou et al. 2005; Widmann et al. 2005;

Bond and Bergstrom 2006; Ram and Sarin 2009; Chow et al. 2009) and other aerosol components (Alfaro et al. 2004; Chow et al. 2000; Lack et al. 2009; Schladitz et al. 2009).

- Pages 2-13 to 2-15 discuss how different co-pollutants of BC (by which this Report really means other parts of the PM mixture) affect the particle properties, but most of the Report refers to BC as a single pollutant with distinct properties. In health studies "co-pollutants" is a term used to describe other pollutants, not other parts of the PM mixture. Although a minor point, it may be worth revisiting that language.
- In addition to describing how the different definitions of BC/EC/OC relate to climate effects (as RF), the chapter should discuss how various BC surrogates relate to other categories of effects (e.g., health outcomes, welfare benefit valuation), which measurements are relevant to which effects, and how these measures compare to model results.

4.1.2. Comparing BC to Long-Lived Greenhouse Gases

Charge Question 4: Does the draft Report adequately explain and appropriately characterize the differences between BC and long-lived greenhouse gases such as CO_2?

To a large extent, the Report adequately describes the differences between BC and long-lived greenhouse gases (GHG), including atmospheric lifetime differences, the differences in direct and indirect radiative processes (including snow and ice albedo effects), the vertical and horizontal distribution differences in the atmosphere, and the much more complicated physical characteristics and atmospheric behavior of BC/BrC/PM relative to long-lived GHGs.

The use of text boxes and tables (such as Tables 2-1 and 2-2) is very helpful in summarizing information. Figure 2-6 and Table 2-2 are particularly clever and informative in their depictions of particles and their evolution over time. The description of uncertainty on page 2-19, lines 10-19, is very illustrative. Perhaps more of these types of text boxes and figures could be developed, particularly in other parts of the Report where uncertainties are described within the text. The Council suggests clarifications and improvements in the following areas:

Model Uncertainty

A central issue has to do with models used as tools to assess impacts, tools to help us understand BC's effects. The Report, however, is nearly silent on the reliability of simulations from the existing models, in that it doesn't say whether these tools are sufficiently sophisticated to capture the complexities of the climate system. The reader needs EPA's key message as to how useful and reliable the model results are.

Climate Response Relative to GHG

Although radiative forcing is a useful metric, the climate response—which involves interactions between all the components of the biogeophysical system (atmosphere, hydrosphere, lithosphere, biosphere, cryosphere)—is more relevant to BC effects on climate. There is merit in presenting the differing contributions of BC and long-lived GHGs to radiative forcing, but it would be more realistic to discuss climate response modeling that takes into account a larger suite of BC direct, semi-direct, and indirect effects than has been done in the various modeling exercises considered by the IPCC and referred to in the EPA report (see response to Charge Question 3, in section 4.1.3 below).

Time Scale

An important consideration when comparing the effects of BC and long-lived GHGs is the time scale over which effects are assessed. The Report provides a clear explanation of the different radiative forcing (RF) over multiple time scales from short-lived particles vs. long-lived gases. Additional references on the different time scales of forcing for BC and GHG include Shindell et al. (2008, 2009) and Unger et al. (2010). A figure showing the RF and dT response to pulses, as well as sustained constant emissions of BC and CO_2, would further illustrate the differences in temporal behavior of these components. (Note that the estimated atmospheric lifetime of CO_2 is constrained by available data to between 30 and 95 years, not centuries.)

The Report strongly emphasizes that BC reductions should not be viewed as a substitute for needed reductions in long-lived GHG over the long term, but is relatively silent on the unique benefits (if any) that might be expected from changes in more near-term influences. A more thorough discussion should be given of these implications and the desirability of placing a higher priority on the control of a short-term climate forcer such as BC than on long-lived GHGs alone. Meaningful reductions in short-term climate forcers could have profound effects on the opportunities for society to implement climate change adaptation as well as to transition to low-carbon economies. To make that case, however, it is essential that the real potential for BC mitigation would be meaningful for the climate system, a point that the Report does not directly address.

The Council suggests that the Report incorporate additional graphics to illustrate the near-term mitigation potential associated with decreasing RF due to BC and other climate forcers (e.g., Figure 1 in Penner et al. 2010; Figures 3 and 4 in UNEP and WHO 2011), with the caveat that the discussion clarify what is included in the calculations behind the figures (which effects of BC are included, assumptions about reductions of BC emissions, reductions of other emissions, efficacy, etc.). Note, for example, that the scenarios shown in Figure 4 in the UNEP report (2011) include both methane and BC reductions. A similar figure showing the effect of BC reductions alone would be useful for the Report.

Another perspective on the nonlinearity of shorter-term climate responses should be mentioned, which is that of "tipping points" (see Kriegler et al. 2009, and "Tipping points in the Earth system" by Timothy M. Lenton, at http://researchpages.net/esmg/people/tim-lenton/tipping-points). In this context, our lack of understanding for triggers of "abrupt climate change" (Alley et al. 2003) and the significance of its consequences warrants a discussion of non-linearity in the climate system and the potential role of BC on shorter timeframes.

Differences in the temporal behavior of BC relative to long-lived GHG also are important when selecting metrics to evaluate various policy goals and mitigation strategies; this topic is discussed further in Section 4.7 in response to Charge Question 14.

Ecosystem Feedbacks

The Report should clearly state that the comparison of BC and GHG does not consider the complex linkage between the climate system and ecosystems, and the differential role of BC and CO_2. Both BC and GHGs, particularly CO_2, can alter ecosystems and thereby potentially influence feedbacks between ecosystems and the atmosphere. For example, CO_2 can enhance plant growth through the well-known CO_2 fertilization effect, capturing carbon through photosynthesis, and increasing water use efficiency of plants through reduced stomatal conductance (IPCC 2007). Both of these effects influence feedbacks for CO_2 and water vapor to the climate system. These physiological effects on plants from CO_2 are largely absent for BC. Terrestrial and marine mechanisms for CO_2 uptake are not infinite, however, which raises concerns for an increasing airborne fraction of CO_2 over time with a decreasing land and ocean CO_2 sink (Canadell et al. 2007), mechanisms not relevant to BC. On the other hand, soot deposition to plant foliar surfaces can inhibit photosynthesis (Kozlowski and Keller 1966), while BC deposition to soils could enhance soil productivity (Laird 2008; Lehman et al. 2006). Climate change can increase wildfire frequency due to increased risks of drought and lightning (Amiro et al. 2009; Liu et al. 2010), resulting in feedbacks of PM and GHGs to the atmosphere.

Although a discussion of climate-ecosystem feedbacks is beyond the scope of the Report, readers should be alerted to the fact that these additional cascades of climate-mediated effects are not included in the Report's analyses of BC mitigation costs and benefits.

4.1.3. Climate Effects

> *Charge Question 5. Does the draft Report appropriately characterize the mechanisms by which BC affects climate and the full range of climate effects of BC (including best available estimates of the magnitude of those effects)?*

In general, Chapter 2 is a well-written, comprehensive description of the various mechanisms through which BC affects climate. However, the draft Report is missing a discussion of some processes that affect climate and could delineate more clearly some terminology related to different processes affecting clouds. Specifically, the Council recommends clarification in the following areas:

Climate Response

The Report should do a better job distinguishing between radiative forcing and climate response and emphasize that radiative forcing terms are not linearly additive so do not necessarily give the full climate effect of a substance. Climate response calculations capture feedbacks and effects not captured by radiative forcing, account for nonlinear interactions and give a better overall assessment of the effects of a pollutant. An example of a feedback is the effect of warming on water evaporation and the additional warming that results from the increase in water vapor mixing ratios. Additional relevant literature on climate response to BC includes Shindell and Faluvegi (2009), Andrews et al. (2010), and Bann-Weiss et al. (2011).

The Report states in one place (p. Ex-2) that GHGs are by far the largest contributor to global warming. This should be modulated to just “GHGs are the largest contributor.” Similarly, the text states in a table (2-1) that BC is the third leading cause of warming, although many studies suggest it is the second leading cause. Thus, the Report should state that BC is “either the second or third leading cause” of global warming.

The Council recommends that several additional effects be discussed and clarified in the Report:

- Cloud absorption effect: Heating of BC inclusions within cloud drops burns off clouds, increasing solar radiation to the surface (Jacobson 2006, 2010; Ten Hoeve et al. 2011).
- Semi-direct effect: BC in the air stabilizes the air and reduces the relative humidity, reducing the vertical transport of moisture and energy to a cloud, reducing cloudiness, increasing the penetration of radiation to the surface (Hansen et al. 1997; Ackerman et al. 2000).
- BC-water vapor effect: The warming of the air due to BC increases evaporation of water vapor, itself a greenhouse gas that triggers further warming (Jacobson 2010).

In addition, the first and second aerosol indirect effects differ from the semi-direct and other cloud effects. A distinction between these various effects should be included in the Report. The cloud absorption effect and semi-direct effects act to warm and evaporate clouds, increasing surface warming whereas aerosol indirect effects tend to thicken clouds, reducing surface radiation and causing cooling. Satellite data suggest that aerosol particles tend to increase cloud thickness with increasing aerosol optical depth at low aerosol optical depth but decrease thickness at mid and higher aerosol optical depths. Note also that the glaciation indirect effect is introduced (on page 2-12, line 13) but is not really described within the section.

Figure 2.8 (page 2-18) should be re-evaluated. Does the cloud lifetime and albedo effect (aerosol first and second indirect effects) exclude other aerosols but BC? If so, is the sign possibly correct? The caveats for the indirect effects are stated in the legend but the title of the figure (Estimates….Black Carbon Emissions Only) could be misleading.

Uncertainty

The Report should provide a more consistent sense of the scientific uncertainty for the indirect effects and overall impact of BC on cooling versus warming. Some statements note that the warming effects "very likely" exceed the cooling effects (e.g., pages Ex-3 and Ex-4) but elsewhere the net effect is "very uncertain" and "thought to be a net cooling influence" (Introduction page 2-2) although warming is "very likely" to exceed cooling (also page 2-2). Later in the section (p. 2-24, line 12), the Report states that "It is unclear to what extent BC contributes to the overall aerosol indirect effect." This statement and the rest of the discussion in the paragraph where this statement appears seem to be key, definitive statements. From them, the reader concludes that not enough is known about BC effects on climate to justify BC mitigation. The Council does not think this is the correct inference to draw based on the preponderance of evidence so far. Based on available data, the Council suggests an affirmative statement that BC appears to warm climate and that BC mitigation would produce both health and climate benefits.

Arctic Impacts

The subject of aerosol transport should be discussed in greater detail so that readers understand fully the implications of Arctic BC/PM effects and ice melt, as clearly most of the emissions sources are not from the Arctic region. This appears to be important since the same applies to other heavily snow-covered regions. Other than saying that emissions impacting the Arctic come from uncontrolled burning of biomass in Northern countries (the Report should list these) as well as agricultural burning, where else are those emissions – particularly those that lead to deposition on the ice – coming from? Does it change by season? What is the role of shipping? The Report (on page 2-40, line 32) attributes 50% of sea-ice retreat to BC, but that seems high; did the studies really attribute retreat as due to BC alone?

Radiative Forcing

As noted earlier, the Council recommends that the Report include a table showing the radiative forcing of BC as a ratio of the mass of BC, and discuss how the mixing state of BC can enhance its absorbing properties. Some of the differences in results from different models as to the forcing from BC could be attributed to the way models treat optical and physical properties of BC (e.g., see Vignati et al. 2010) and also the amount of BC that is present. It would be helpful to include a table showing forcing and associated physical and optical properties treated in each of the models to shed light on the different forcing results obtained from the models.

The EPA report would benefit from more quantification of how much BC emissions contribute to warming and the potential for reduction in global temperatures from BC mitigation. The recent UNEP assessment (UNEP and WMO 2011) could be referred to here, but it is important to clarify how the calculations there are done and the underlying assumptions. It should also be clarified how much of the calculated reductions in temperature can be attributed to BC reductions (i.e., separate the BC effect from the effects of other components reduced).

In general, when results from the literature are cited and compared, the Report should indicate which effects are included in the model studies and how these are implemented since different set-ups and design of model studies may explain much of the differences in results. Other suggestions include:

- Page 2-33, Lines 7-15: A useful addition is to also account for how much change is present between PD and PI BC amount when characterizing forcing ranges between different studies.
- Page 2-45, Table 2.6: It would be useful to include a regional distribution of radiative forcing effects.
- The discussion of seasonality (the temporal aspects of emissions and effects) could be expanded, as well as the importance of the short life-span of BC’s effects.
- To reflect the spread in published estimates of RF, the Report should include a reference to Aunan et al. (2009) and their results for RF from household fuel burning in Asia.

Economic Valuation

The Council recommends that Section 2.7 (Economic Value of BC Impacts on Climate) be deleted, and that valuation of the BC impacts be consolidated and treated more comprehensively in a separate chapter. (Recommendations on the treatment of economic benefits and costs of BC mitigation are discussed in section 4.6).

4.2. Effects on Public Health and Environment

4.2.1. Public Health Effects

Charge Question 6. Does the draft report accurately summarize and interpret the body of scientific evidence relating to the potential public health effects of BC?

Chapter 3 of the Report provides a brief overview of the health impacts of particles that is lacking in detail and sophistication compared to other parts of the Report. The Council recommends that this chapter be expanded, and that health be given more of a focus throughout the document. In particular, the executive summary should include a stronger focus on the health benefits of lowering BC emissions, and should mention health earlier in the text. Currently, the executive summary's mention of health (page Ex-5) is under-stated, and the imbalance and sequencing reduce the impact that the document could otherwise have. Below are some specific suggestions:

Uncertainty

While there is uncertainty regarding the health impacts of BC, the Report should highlight that this uncertainty relates to the differential health impacts of any individual PM component or sources relative to PM as a whole, rather than from a lack of knowledge about BC specifically. As written, the Report may give the impression that there is disproportionately more uncertainty about BC than other PM components. In fact, there are many studies that relate BC to health, including studies that examine sources of BC rather than BC itself. Relevant studies include land-use regression modeling to estimate traffic exposure (especially in countries where conventional diesel vehicles are prevalent), proximity studies that estimate exposure based on distance from major roadways, and indicator components (which may or may not be BC) for general traffic or diesel sources. There are numerous studies available, and this report does not need to be a comprehensive list, so the Council will leave the choice of studies to the EPA. Some studies that could be added are those that provide evidence for respiratory-related illness (see Ostro et al. 2009; Beelen et al. 2008; Maynard et al. 2007; Clark et al. 2010; Morgenstern et al. 2008).

In addition, the text describing the uncertainty around source apportionment may give the impression that such results are not meaningful. However, despite the uncertainties, multiple source apportionment methods have shown that similar results are achieved (e.g., see Thurston et al. 2005). The Council also recommends adding more source apportionment references in general, as the Report ultimately emphasizes source-specific control strategies that would capture the mixture of pollutants from these sources.

Expand the Discussion of BC Health Effects

While it is reasonable to rely on the most recent Integrated Science Assessment (ISA) for particulate matter (U.S. EPA 2009) as the foundation of Chapter 3, given its relevance and the amount of effort that went into its compilation, this approach leads to some holes in the chapter. For example, the ISA includes studies only within defined dates and primarily focuses on studies relevant to the regulation of total $PM_{2.5}$ mass. There is also significantly more detail in the ISA than in Chapter 3, some of which could be leveraged to give a richer portrayal of the evidence. The Council does not recommend an extremely lengthy chapter, but targeted expansion to inform the readership about a few key points.

- The relevance of the $PM_{2.5}$ literature for BC could be discussed in more detail. Of $PM_{2.5}$ chemical components, BC is one of the larger contributors to $PM_{2.5}$ total mass. For example, Bell et al. (2007) examined level of PM components on a national basis, and identified EC as one of the seven main contributors. While this large mass from BC does not preclude the possibility that other smaller contributors are harmful for human health, the large contribution of BC to $PM_{2.5}$ indicates that BC is one of the candidate constituents explaining the $PM_{2.5}$ health effects, and studies of $PM_{2.5}$ total mass are therefore relevant to the health impacts of BC.
- The Report also correctly refers to numerous studies on BC specifically and related pollution measures, though discussion of BC-specific studies should be expanded. Many epidemiological studies are not focused on BC, but use EC or a source (e.g., traffic). In fact, even in single pollutant studies, the BC may be considered an indicator pollutant for all traffic-related emissions. This concept should be discussed in the text. As mentioned above, the evidence linking BC to health effects is not just from those that studied BC directly, but from a broader set of studies that include traffic, etc.
- The Report repeatedly notes that BC is often emitted with other pollutants, such as other types of particles. However, the reader may infer that there are BC particles and other particles emitted at the same time, and that these are entirely separate entities. In reality, BC is part of a complex mixture within a single particle. This should be highlighted early in the Report when types of carbonaceous particles are defined.
- The spatial variation of BC is an important point that is made in the Report and in the executive summary. Figure A provides an example of the U.S. versus global emissions, which might imply less variation with the U.S. Including the figure is fine, but interpretation would be aided by mention of the within-U.S. variability. Information on spatial variability of BC would help provide more specific guidance about optimal locations for intervention strategies, and could also be discussed in Chapter 3 in relation to possible exposure misclassification and underestimation of health effects of BC relative to some secondarily formed particle constituents.

Co-Benefits

The concept of co-benefits could be greatly expanded in Chapter 3 and throughout the Report (e.g., Chapter 6). Relevant additional studies that could be added include Li et al. (2011), Huang et al. (2011), Ganten et al. (2010) and Bell et al. (2008). The Council also recommends that the concept of co-benefits be discussed further in the Executive Summary, which could be re-oriented to emphasize that there would be "no regrets" strategies available to mitigate climate change if (as seems likely) the public health benefits of BC control strategies outweigh the costs. EPA's most recent assessment of the Benefits and Costs of the Clean Air Act (U.S. EPA 2011a) could be referenced with specific numerical examples of the relative impact of particles on human health. This is an excellent way to use EPA's existing studies to provide quantitative evidence of the health, and related economic, benefits of reducing particulate matter levels. Chapter 6 provides the dollar-per-ton health benefit estimates from one study, but other quantitative insight is available from previous work and should be discussed. In particular, the concentration-response functions for mortality, which are the foundation of the dollar-per-ton health benefit calculations and related conclusions, are never discussed explicitly or presented in Chapter 3 or elsewhere.

Economic valuation

The economic valuation section of Chapter 3 provides a general overview, but not specifics. The Council recommends that the economic valuation text be removed from Chapter 3 and included in a new consolidated chapter on benefits and costs, and that the discussion of health benefits be expanded either to provide selected results or explicit reference to other sources. If expanded, it should provide a very careful definition of "value of a statistical life" (VSL) for the uninitiated reader, and talk about the values typically used in regulatory analyses. (Recommendations on the treatment of economic benefits and costs of BC mitigation are discussed in section 4.6).

4.2.2. Non-Climate Environmental Effects

Charge Question 7. Does the draft report accurately summarize and interpret the body of scientific evidence with regard to potential non-climate environmental (welfare) effects of BC?

The Report provides a very brief (two-page) summary of the effects of "$PM_{2.5}$, including BC" on ecosystems, on damage and soiling of building materials, and on visibility. As with the preceding discussion of health effects, the implication that welfare effects are only associated with BC as a fractional contributor to $PM_{2.5}$ mass seems like an unnecessary generalization. Where information specific to BC is not available, it would be helpful to identify models that could be used; for example, the Forest and Agricultural Sector Optimization Model (FASOM) in looking at agricultural impacts (see U.S. EPA 2011a).

Effects of BC on visibility have been relatively well characterized in the literature, and could be described separately from those of other $PM_{2.5}$ constituents. The Report does discuss visibility effects of "carbonaceous aerosols" (BC and OC), but could provide more detail specific to BC. For example, at relative humidity below about 85 percent, BC contributes to light extinction more efficiently per unit mass than any other $PM_{2.5}$ species. Thus, under most conditions, and especially in populated urban areas, BC's contribution to visibility impairment is typically greater than its proportionate contribution to $PM_{2.5}$ mass. BC's extinction efficiency can be enhanced in internally mixed aerosols combining BC with non-absorbing species like sulfates or organics. In addition to effects on light extinction, BC (and BrC) also can cause or substantially contribute to atmospheric discoloration effects (i.e., layered haze, Denver Brown Cloud, etc.), which people often find especially objectionable. Thus, the aesthetic effects of BC and BrC on visibility impairment are greater than their contributions to light extinction alone.

The Report's approach of collectively summarizing effects of "$PM_{2.5}$, including BC" also is not well suited for reviewing effects on ecosystems and crops. For example, the ecological effects of PM discussed in the second paragraph of section 3.4 are due to PM components (metals or toxic organic compounds) other than BC. Conversely, the BC (and BrC) contributions to (surface dimming-related) reductions in crop yields (discussed in the third paragraph of section 3.4), or on the productivity of forest ecosystems, are likely to be of a distinctly different nature than those resulting from most other (light-scattering) aerosol components. Both absorbing and scattering aerosols reduce the amount of direct photosynthetically active radiation (PAR) reaching leaf surfaces, but the increase in indirect diffuse radiation resulting from scattering aerosols can lead to increases in photosynthesis and net primary productivity under some conditions. In contrast, light-absorbing aerosols decrease direct radiation but do not contribute to these increases in diffuse PAR. Cohen et al. (2002) found that the net effect of PAR scattering and absorption by atmospheric aerosols on net primary productivity (NPP) can be positive, neutral, or negative. For additional detail on this topic, see Yamasoe et al. (2005), Greenwald (2006), Oliveira et al. (2007), Matsui et al. (2008), Betts and Silva Dias (2010). It is important to recognize that in some countries, the impact of BC on crop loss is extremely important and therefore the Report should give this subject the appropriate attention.

A more minor point is that these non-climate effects need to be carried forward when discussing benefits. The treatment of the economics of these impacts is incomplete, in part because the literature on the impacts is not translated into endpoints that are economically meaningful. For example, there is no description of the practical significance of the measured changes described in the literature. Are the changes in crop productivity large enough to have price effects? How these effects are measured (the metrics for impacts) would determine what valuation literature is applicable. In other words, a measured environmental effect is not equivalent to a welfare effect. The Council suggests that rather than adding details of the valuation methods to chapter 3, the current section on valuation (section 3.5) be moved into a new chapter on valuation of these and other endpoints. The new chapter should include a more detailed and rigorous description of methods to value the change in these endpoints (see section 4.6, below, in response to questions 12 and 13).

4.3. National and Global Black Carbon Emissions

4.3.1 Past and Present Emissions

Charge Question 8. Does the draft report appropriately characterize available information on historical, current and future emissions of BC and related compounds in the United States and globally, and present this information clearly?

Source Characterization

The Council recommends that the authors clarify several aspects of the discussion of source characterization across combustion sources, national domains, and source categories.

First, the Report refers to "domestic sources" but this term is not clearly defined. For example, do domestic sources include international sources operating in U.S. territories? Similarly, there are U.S. sources operating outside U.S. domains; this has special relevance for the important discussions related to the Arctic, and to shipping in general, with other locations and sources possibly included. In particular, the category "commercial marine" needs clarification. The number of marine diesel engines is small, although the installed power can be very large. These engines can be operating in the U.S. but be international; operating internationally under U.S. registry (flag); or be both U.S. registered and operated within U.S. waters (e.g., harbors, inland rivers, coastal waters, and the Great Lakes).

Second, the term "contained combustion" is used in Chapter 4 but only poorly defined in Chapter 8, Section 8.3, for the first time. While used by some scientists in papers and reports, this is not a common term for engineering disciplines. Engineering and scientific combustion types may jointly include: (a) open burning (biomass); (b) open combustion (inclusive of steam boilers, some gas turbines); and (c) closed combustion (internal combustion, reciprocating diesel engines). Some discussion of this "taxonomy" (along with the glossary suggested by the Council and in-text definitions of the adopted terms) would make Chapter 4 clearer to readers across disciplines.

Third, the characterization is really aimed at diesel engines using distillate petroleum fuels. This is not strictly correct, and it affects the technologies discussion later in the Report; in fact, technologies that do NOT require distillate petroleum (or more importantly, U.S. ultra-low sulfur diesel fuel, ULSD) may be appropriate to consider – both for larger diesel engines in mobile and stationary service, and in addressing global (non-U.S.) diesel systems.

Figure 4-1 is a very important graphic requiring integration with characterizations of sources later (see discussion under uncertainty).

Geographic Characterization

The draft Report focuses primarily on nationalities of sources, poorly representing sensitive regions like the Arctic. Sensitive regions can be discussed from at least two perspectives: (a) sensitive regions for climate response; and (b) sensitive regions for health risk exposure and impact. These two perspectives should be presented in parallel throughout the Report since the relevant geographic areas often differ. It becomes important when chapters on "metrics" are really climate response metrics, and when chapters on social cost metrics are often (not always) health risk valuations of mortality and morbidity.

The Arctic is a sensitive response region primarily with respect to climate change, although there are communities impacted by air pollution (at least globally) in and around the Arctic front (above 40° N latitude). This can be introduced in Chapter 4 discussion with greater clarity linking to later chapters.

Despite the emphasis elsewhere that the Arctic is an important sensitive region of interest to the EPA, it is unclear how BC and OC emissions in the Arctic region are characterized or allocated among the national domains reported in Tables 4-4 and 4-5 of the Report. As noted above, the information used to characterize international and geographically important emissions is unclear and incomplete. For example, shipping is stated to be included in sources for Tables 4-4 and 4-5, but may not be allocated in domains, given that activity occurs outside national boundaries.

Arctic importance can be better presented through additional citations to Arctic work (e.g., the Arctic Council's 2009 Arctic Marine Shipping Assessment; Skeie et al. 2011). The Report also should reference recent regional inventories for Arctic Shipping (Corbett et al. 2010a; Peters et al. 2011), and for global shipping with special regional attention to Arctic emissions (Paxian et al. 2010). It is not until Section 4.4.2 that the Report discusses which areas might be important contributors to Arctic BC impacts.

The discussion of emissions above 40° N latitude mainly discusses U.S. emissions above this latitude without sufficient context for other nations' emissions. For example, Table 4.7 could be expanded to include relative contributions of BC from all countries and sources north of the 40th parallel. Similarly, Figure 5-2 which could be improved with shading below the dotted line to focus and connect discussion of the region above 40° N latitude – and the figures and tables could include shipping.

Scientific understanding of geographic effects on emissions characteristics (and perhaps on modeling of impacts, on uncertainty, etc.) is not well articulated. This includes seasonality patterns (e.g., temperature, activity).

Global comparisons seem arbitrary. The purpose of similarity analysis by nation should be clarified, with attention to the readership that will include other nations and global scientists or policymakers outside of EPA and beyond Congress.

Accuracy and Uncertainties

The Report discusses uncertainty, but without providing a sense of the overall weight of evidence – no judgment from the analysis emerges to provide context for the Congress or other readers. For example, does uncertainty in emissions source characterization have higher priority or does it contribute more uncertainty than modeling of atmospheric processes, or social benefit-cost uncertainties? Without context, the Report seems too uncertain for the confident conclusions about emissions source characterization – especially global comparisons.

This can be partly addressed by attention to language: e.g., the Report could/should use "estimates of emissions" and more fully recognize the uncertainties. It is important to articulate source uncertainty in comparison with other uncertainties discussed: for example, process model uncertainty, BC v. BrC, mixing, metrics. Do emissions uncertainties dominate or pale by comparison? By doing so, the overall power of conclusions about mobile source dominance, biomass burning variability, etc., will be more adequately conveyed. The Council encourages EPA to articulate prospects or plans for reducing emissions uncertainties and for propagating these into the overall summary of insights for emissions, their impact on modeling confidence, social costs, and metrics. Propagating these uncertainties may be beyond this report, but it offers great opportunity to strengthen the insights drawn in the study.

For example, the RPO v. EPA details on biomass burning could say, "Nonetheless, biomass burning BC estimates remain more uncertain than engine combustion BC because of year-to-year variability and for other reasons addressed in this chapter."

Regarding Tables 4-4 and 4-5 in the Report, uncertainties (or variability) presented absolutely affect (confound) the ratios presented comparing emissions from other countries with U.S. BC emissions. This comment applies to many bar graphs and comparisons as well, and should be carried into these discussions (at least in Chapter 4). Grouping sources into categories is useful in the discussion and Figure 4-1 (p. 4-4) should be organized in accord with those categories rather than alphabetically. Uncertainties depicted in that figure (see Figure 4, below) undermine the attempt at global comparisons, mostly by being presented with apparent over confidence; based on the uncertainty in emissions from biomass burning, for example, the U.S. ranking cannot be claimed to be sixth with any confidence (see Figure 5, below).

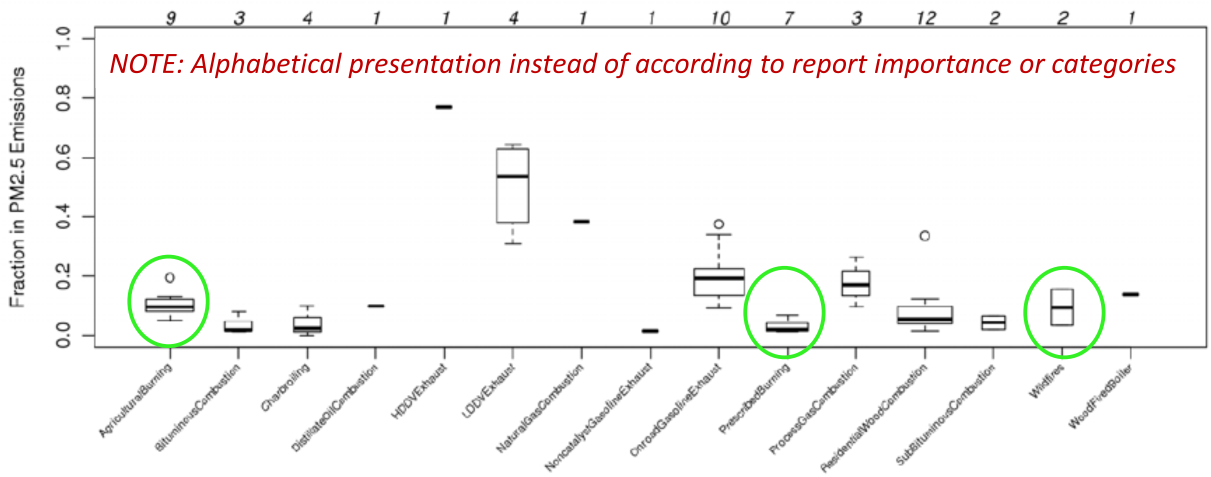

Figure 4. Contribution of Various Sources to PM2.5 Emissions and Associated Uncertainties (modified from Figure 4-1 in the Report).

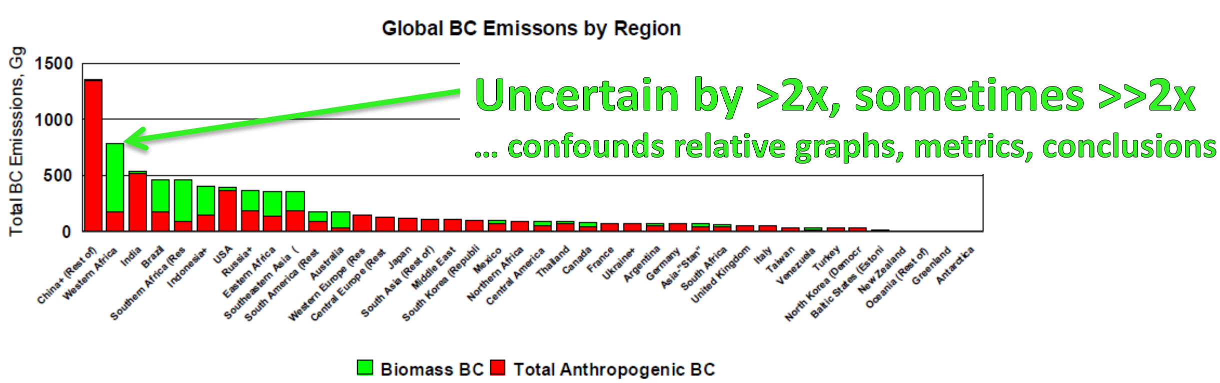

Figure 5. Uncertainties Confound Conclusions about Relative Contributions to Global BC Emissions (modified from Figure 4-10 in the Report).

4.3.2. Transport and Location of Effects

Charge Question 9. Does the draft report accurately summarize and interpret currently available information regarding the transport of BC emissions downwind of sources and the relationship between the location of emissions sources and the geographic region of climate and non-climate impacts?

The Report addresses the issues involved in the long range transport of BC at an appropriate level of detail, although a couple of additions are warranted. First, the Report should mention that aircraft are a major direct source of BC emissions over the Arctic. Ice-breaking ships and ships that follow them are close sources as well. Aircraft BC emissions over the Arctic persist longer than do surface BC emissions since they are emitted into the stable stratosphere, primarily. They are also emitted above clouds and ice, so absorb not only downward but also reflected upward radiation. A paper quantifying and showing visually the aircraft emissions over the Arctic is Wilkerson et al. (2010). Papers examining the long-range range transport of BC to the Arctic from ground sources include Liu et al. (2011) and Matsui et al. (2011).

Second, the Report should point out that BC particles become more internally mixed during long-range transport, increasing both their warming effect due to optical focusing and their hygroscopicity (i.e., ability to retain moisture). This internal mixing increases the ability of BC particles to participate in the indirect effects, the semi-direct effect, and the cloud absorption effect. It would be appropriate to discuss the uncertainties associated with both of the above issues, as well as the relative uncertainties associated with BC transport in comparison with other issues.

To differentiate between global ("background") warming and effects associated with regional BC sources, the report could summarize results in the literature on contributions to RF and warming globally and at high latitudes (e.g., Reddy and Boucher 2007; Rypdal et al. 2009a; Shindell and Faluvegi 2009). The Report should also discuss how heterogeneous and localized RF (e.g., from emissions in the same region) may trigger temperature responses that may be different than those of the long-lived forcers (e.g., from global sources).

As noted previously, the subject of aerosol transport to the Arctic and the Himalayan plateau could be bolstered to facilitate a better understanding of the implications of BC/PM effects on ice melt in these regions. This is also important since the same applies to other heavily snow-covered regions where the implications for decreases in snow cover, depth, and the timing and distribution of snowmelt have important societal and ecological consequences.

4.4. Observational Data

Charge Question 10. Does the draft report appropriately characterize and interpret the information on BC that is available from the observational record?

Chapter 3 nicely describes what is known about BC from the most current observational record. The results presented are very appropriate and reasonably complete. The inclusion of satellite observational data is timely as this presents an emerging field with potential, when uncertainties are resolved, to address many of the key data gaps associated with the current approach for monitoring ambient concentrations of BC and, for that matter, other pollutants. This chapter also introduces the practical aspects of BC measurement, including the operational definitions of BC based on the measurement methods used. The discussion is difficult because of the complexities, intricacies, and nuances, not the least of which is using the same designation for what are really different measurement methods.

Some of the figures may contribute to this difficulty in that they appear to have been translated from their original sources with incomplete footnotes, captions and legends. These oversights are noted below. However, Figure A1-1 in the first appendix is a very effective graphical representation of methods and definitions. As noted previously, the Council recommends that this figure be included in the main body of the Report to aid in the explanations concerning definitions and methods.

The references to the sources of data are pertinent and up to date, although there are numerous additional ones of relevance that are indicated in the specific comments below. In the discussion of sediment records, only a subset of the referenced data is presented. No characterization is given of the findings from any of the references cited in the second paragraph of section 5.6.4. This is understandable if the intent is to focus on data for the U.S. as well to control the size of the Report, but a brief characterization of these papers might be provided.

BC Trends

The long-term BC downward trends (p. 5-1, lines 26-29) in the U.S. are an important finding that should be moved up the list of key messages, possibly to a first bullet. The data provide evidence that emission reduction efforts in the U.S. have worked to date, including emission reductions associated with engine and fuel improvements (Bahadur et al. 2011; Kirchstetter et al. 2008; Minoura et al. 2006; Murphy et al. 2011) and reductions in residential biomass burning emissions (Burnet et al. 1988; Butler 1988; Hough et al. 1988) to attain NAAQS (Bachmann, 2007) for PM and other pollutants. However, U.S. emission regulations still leave significant room for further reductions in BC from several source categories. Further, despite the evidence of declining BC emissions in the U.S., the Council cautions that trends in BC emissions in other parts of the world are rising. Increases in population and/or in the number of emitting devices are likely to offset progress to date without specific policy attention to these global drivers of BC emissions. Therefore, the Report should emphasize the observed reductions in BC in the U.S. to highlight for Congress that there is added benefit to what is being done already, as well as to encourage other countries (e.g., China and India) to consider climate benefits as they weigh further emission reduction measures. This should be elevated to a major report conclusion.

Averaging period

EC and BC concentration ranges (p. 5-1, lines 10-15) should apply to a consistent averaging time (e.g., 24-hours, annual average, seasonal average). Cao et al. (2007) found wintertime average EC values exceeding 15 µg/m^3 in two Chinese cities. Short duration spikes (as seen on aethalometers when a diesel truck passes) can be higher, even though a longer term average would be lower. Winter BC averages are typically higher than summer averages. The Report might note that wintertime urban averages can exceed 20 µg/m^3 and adjust Table 5-2 to match. The 5 to 10 percent of $PM_{2.5}$ estimate (p. 5-1, line 16) also needs some qualification with respect to location and averaging time. This range seems to be based on Figure 5-4 which is a limited picture of concentrations and may be incorrect (see specific comments below). Figure 6 in VIEWS (2010) shows plots of major components from four urban areas; EC seems to be lower than 5% for many of the samples.

Measurement Variability

The key message regarding measurement variability (p. 5-1, lines 3-7) should be more positive and succinct, such as, “BC and EC values from different measurement methods are highly correlated, although the method-defined absolute values may differ by a factor of two or more. However, self-consistent measurements in long-term networks are sufficient to detect trends that correlate with emission reductions.” This statement would be supported by the general explanations of BC, EC, BrC, and the relationships between them in Chapter 2 and a more detailed treatment of the complexities, knowns and unknowns in Appendix 1.

Chapter 5 should emphasize the need for further research to standardize measurement methods; for example, by including a separate key message on this topic (p. 5-1, lines 7-9). The chapter also might note that $PM_{2.5}$ OC/EC measurements are currently standardized and consistent among the long-term U.S. networks of IMPROVE (IMPROVE 2011), CSN (U.S.EPA 2011b), and SEARCH (ARA 2011).

There are two important sources of variability in BC measurements: (1) differences among thermal measurement methods, and (2) the application of factors to convert optical readings to estimates of particle mass. Two widely cited comparison studies (Schmid et al. 2001; Currie et al. 2002;) show that inter-method differences from EC thermal analyses can easily differ by a factor of two, and Currie et al. (2002) found differences up to 7 times. This is true even for methods with the same designation, such as Thermal/Optical Transmittance (TOT) (Schmid et al. 2001). On top of this is the natural and methodological variability of the mass absorption coefficient (m^2/g) that converts optical measurements of aerosol absorption (Mm^{-1}) to BC. This efficiency varies based on the size distribution and form of the aerosol (see Figure 3 in Schuster et al. 2005), as well as on the methods used to determine light absorption, which differs by a factor of 2 for light transmission through Teflon or quartz fiber filters (Chow et al. 2010).

The Report should emphasize that optical devices do not measure carbon; rather, they measure light absorption or attenuation at different wavelengths and then BC particle mass is estimated using default mass absorption efficiencies set within each instrument. A column should be added to Table A1-2 to indicate the different wavelengths used, and to show the default mass absorption efficiencies used in each instrument to estimate BC. This is a major cause of uncertainty in estimates of ambient BC.

Despite the statement in the Report (page 5-3, line 24) that the mass absorption efficiency is an “issue of debate,” it is known that there is no single factor that is applicable to all methods, wavelengths, particle sizes, particle compositions, shapes and structures. Theoretical and empirical studies show that bounds can be placed on absorption efficiencies for different assumptions of the aerosol origins and compositions (Alfaro et al. 2004; Andreae et al. 2008; Chan et al. 2010; Chou et al. 2005; Chow et al.

2009; Dasgupta et al. 1991; Dillner et al. 2001; Favez et al. 2009; Fu and Sun 2006; Fuller et al. 1999; Horvath 1993; Jacobson 1999; Jacobson, 2000; Jacobson 2005; Jacobson 2006; Liousse et al. 1993; McMeeking et al. 2005; Nordmann et al. 2009; Ogren et al. 2001; Ram and Sarin 2009; Ramana et al. 2010; Rosen and Novakov 1983; Schuster et al. 2005; Wagner et al. 2009; Watson et al. 2005; Widmann et al. 2005).

The suggestion (page 5-3, lines 27-28) that the ideal solution is to quantify BC in light absorption terms should be qualified, since light absorption is measured variously *in situ* by photoacoustic spectroscopy and as the difference between light extinction and light scattering and on filter media, or approximated by reflectance off filter media. All absorption approaches are subject to interferences from light-absorbing substances other than BC. Even if using light absorption equivalent, it should be understood to be different than mass of BC (or EC). Unfortunately, from the perspective of practicality, the only ideal method might have to be particle-by-particle characterization of morphology, internal structure and composition, and optical properties as a function of relevant wavelengths.

Additional relevant studies

More than 100 BC/EC/BrC comparison studies have been published and these studies could be referenced in Chapter 5 of the Report. See Table 2 of Watson et al. (2005) and Table C-1 of Chow et al. (2006) for summaries of comparisons up to 2006. Additional comparisons among a variety of measurement methods have been published since then (Bae et al., 2007; Bae et al., 2009; Braun et al., 2007; Calvello et al., 2010; Chan et al., 2010; Cheng et al., 2011; Cheng et al., 2010; Chow et al., 2010; Corrigan et al., 2008; Cross et al., 2010; Flores-Cervantes et al., 2009; Fujita et al., 2007; Gan et al., 2010; Gilardoni et al., 2011; Hammes et al., 2007; Han et al., 2007; Hansen et al., 2010; Hopkins et al., 2007; Hsieh and Bugna, 2008; Kanaya et al., 2008; Knox et al., 2009; Krecl et al., 2007; Lack et al., 2008; Lee et al., 2007; Miyazaki et al., 2008; Moteki and Kondo, 2007; Moteki and Kondo, 2010; Muller et al., 2011; Niu and He, 2010; Nordmann et al., 2009; Paredes-Miranda et al., 2009; Poot et al., 2009; Quincey et al., 2009; Quincey, 2007; Reisinger et al., 2008; Schaap and van der Gon, 2007; Sedlacek and Lee, 2007; Slowik et al., 2007; Snyder and Schauer, 2007; Subramanian et al., 2010; Taha et al., 2007; Viana et al., 2007; Wallen et al., 2010; Wonaschutz et al., 2009; Zencak et al., 2007).

Presentation of $PM_{2.5}$ Trends in the U.S.

Chapter 5 includes a figure (Figure 5-4 on page 5-12) that shows $PM_{2.5}$ composition for a number of urban areas, but the figure does not seem consistent with recent urban values (e.g., see Figure 6 from VIEWS 2010). The southern California sulfate values are too high in Figure 5-4 and there is no rationale provided for the selection of the cities shown. It might be more relevant to use regional values from the IMPROVE network, as the broader spatial distributions represented by these data would be more relevant to climate. The Figure 5-4 key, caption and footnote 10 are inconsistent. The footnote suggests OM is displayed and calls it organic matter, the caption refers to OM as Organic Carbon Mass (which would be OC), and the key says Organic Carbon. Usually when one displays PM composition in a pie chart, OC has been converted to OM using some multiplicative factor, typically, 1.4 to 1.8. What was done? It appears that the yellow and red slices labeled “sulfate” and “nitrate” also include associated ammonium, and if the figure uses Neil Frank’s SANDWICH approach, it also probably includes some associated water. If true, or approximately so, the legend species names should be changed to “Sulfates”, “Nitrates” and “Organic Matter”, and in the caption, replace “Organic Carbon Mass” with Organic Matter”.

4.5. <u>Mitigation Approaches</u>

Charge Question 11. Does the draft report accurately reflect and clearly communicate information on the available technologies, control strategies, and costs of reducing BC emissions in various sectors? Are there additional control technologies or mitigation strategies for specific sources or sectors that have significant potential to reduce U.S. or global BC emissions that should be included in the Report?

Chapters 6 to10 present an overview and more detailed discussion of the options for reducing BC emissions from mobile, stationary, residential and open burning sources. In general, these chapters present fairly detailed information on technologies and control strategies that could be used to reduce BC emissions from these specific sectors. From a policy perspective that may be of interest to Congress, there is a significant opportunity for international leadership by the U.S. in transferring technologies and programmatic expertise to assist other countries with implementing BC emissions reduction programs in areas such as stationary sources, mobile sources, residential cooking, and open burning. With appropriate assistance and judicious strategies for technology development and transfer, developing countries may be able to leapfrog directly from very high emissions to very low emissions technologies, rather than follow an incremental transition path over a long time period. However, the Council had concerns about the likelihood that certain mitigation options (e.g., improved cookstoves) would be widely implemented in the near future.

Questions did arise, however, on details related to health effects and BC-specific mitigation. These are discussed on a chapter basis below.

4.5.1 Overview of Mitigation Options (Chapter 6)

Chapter 6 presents a good overview of the current state of understanding of BC mitigation options and the Summary of Key Messages appropriately reflects the content of the chapter. The overview of the impact of trends in BC emissions and role of some key emissions management programs is helpful. However, the Council recognizes that it may be challenging to implement many of the control strategies described in these chapters in the developing world. The Report's discussion of mitigation options is of particular importance and is the very core of the Congressional charge for this work. The diversity of sources and the mitigation options pertaining to each source category makes it a challenging endeavor to present them in a logical and useful way for the generalist reader. The analysis shows that there is a range of costs associated with BC mitigation from sector to sector. These differences should be highlighted as a potential means of prioritizing among approaches across sectors. Also, a more developed discussion on uncertainties is important, in particular with respect to mitigation of OC versus BC (and BrC).

The discussion of climate impacts is focused mostly on changes in global mean temperature. Some implications for other endpoints are briefly mentioned but could receive further discussion. The differences in how various models treat BC external versus internal mixing should be discussed so that differences in model results from either physical, chemical or optical properties may be evaluated more critically. In addition, the effects (positive/negative) of atmospheric brown clouds warrant more discussion since virtually nothing is discussed regarding changes in rainfall, reduced UV radiation at the surface, and other effects.

The studies of global BC emissions trends presented in the chapter were published in 2004, at the very beginning of the significant upsurge in primary energy consumption that occurred in China throughout the 2003-2008 period (e.g., see Figure 6 below, and IEA 2010), the vast majority of which is generated from fossil fuel combustion (approximately 70 percent from coal and 20 percent from oil). The Report should discuss the potential impact of this trend on global BC emissions from all energy-related combustion sectors.

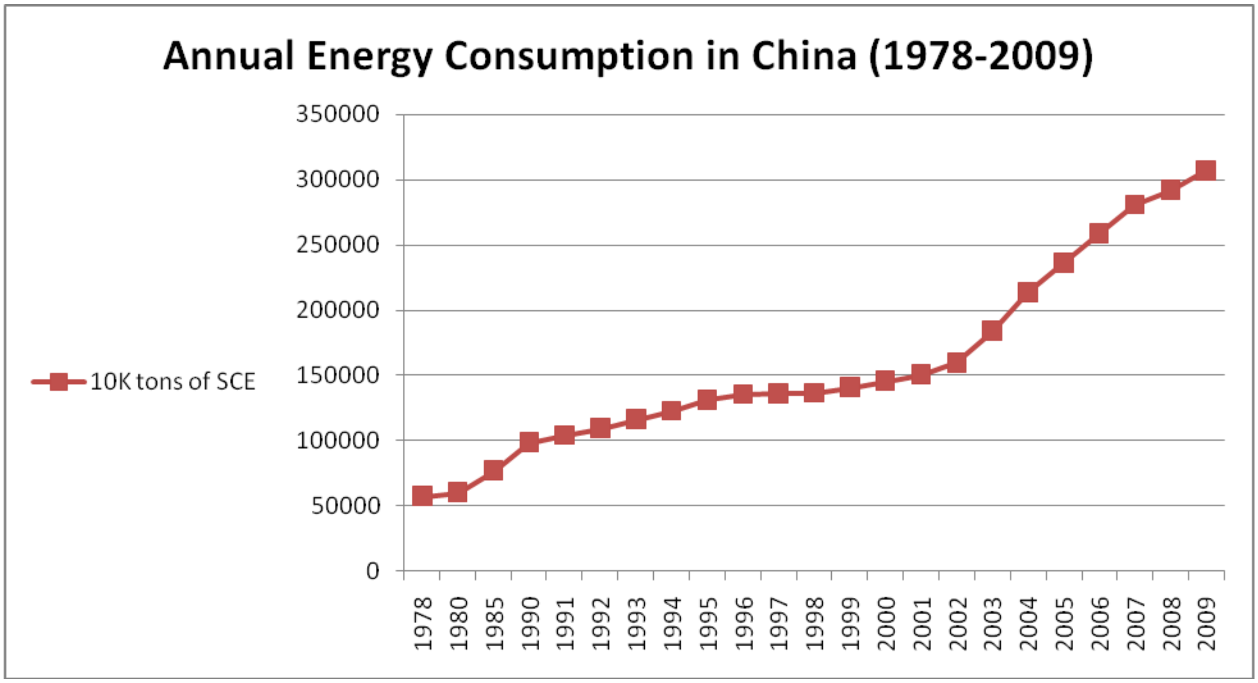

Figure 6. Annual Energy Use in China, in Standard Coal Equivalents (SCE) (Data from National Bureau of Statistics of China, at http://www.stats.gov.cn/tjsj/ndsj/2010/html/G0702E.xls)

Abatement Technologies

Much of the mitigation discussion in the Report was focused on control options available for the conventional diesel engine used in mobile applications. This is justified given that the conventional diesel engine is the largest contributor to the BC inventory for the transportation sector. However, the Report's conclusion that low-sulfur fuels are a precondition for BC mitigation is not strictly correct for all diesel sources. The Council suggests that the discussion of technology options include the following additional points:

- Diesel engines use many fuels, but the Report implies that diesel fuel is of one type – especially through its focus on onroad diesel engines. Large stationary diesels, commercial marine, and other applications using diesel engines would not fit the dominant description. The Report should avoid over-generalizing and thereby leaving the impression that U.S. onroad technologies (and ultra-low sulfur diesel, ULSD) will be preferred solutions for global BC mitigation. In fact, emissions from these other internal combustion diesels using nonroad (non-distillate) fuels are not suited to mitigation using catalytic diesel particulate filters (DPF); for example, the EPA lower fuel-sulfur standard for marine engines specifies 1000 ppm (ECA standard), a level of sulfur that is too high to allow for the use of catalytic DPFs (e.g., see Corbett et al. 2010b).

- All other characteristics being equal, diesel engines are currently more efficient than spark ignition engines and emit less carbon dioxide but the gap is narrowing and very often the characteristics differ. For example, diesel engines tend to be heavier and there is evidence that purchasers of diesel cars drive more than purchasers of spark ignition vehicles, both of which offset fuel savings or CO_2 benefit. Further, unless they are equipped with advanced pollution controls including wall flow particulate filters, diesel vehicles emit much more BC than spark ignition vehicles[2], thereby offsetting climate benefits associated with lower CO_2 emissions per mile. Unless they are equipped with advanced PM controls, it is not clear that diesels provide any significant climate benefit.
- The terms “conventional diesel” vs. “clean diesel” vs. “other diesel” should be clearly distinguished in the discussion because of differences in emissions (and mitigation options) for the different types of diesel fuels; since 2007, most new diesel engines are “clean” diesel, meaning they reflect the use of advanced design, including after-treatment such as DPF which eliminates soot or BC.
- The draft Report, Section 4.3.2.4, says, “Existing EPA regulations for new engines in this category will result in future BC reductions through the use of diesel particulate filters (DPF) , although these controls will not apply to existing engines.” However, U.S. EPA (2003) notes that, “Using pollution control devices such as diesel particulate matter filter (DPF) is one way existing engines can be upgraded (or retrofitted) to pollute less.” Existing engine technologies (DPFs) are more applicable than EPA articulates, and the last part of this sentence should be deleted.
- The chapter should cite the technology that shows potential for non-catalytic DPFs, emulsions and other technologies (e.g., Corbett et al. 2010b); this technology will not address the majority of BC from non-road mobile sources in the U.S., but it will be a faster and less costly path to reductions for some diesel sources.
- The Report refers to on- and off-road land transport and diesels. However, it is not clear if and how the former is inclusive of the latter. In other words, diesel can certainly be part of land transport both in the off-road and on-road category. Conversely, land transport, both on-road and off-road can include depending on the category (i.e., engine size) other fuels (i.e., gasoline) nearly exclusively.
- The Report’s technology focus ignores possible systems effects, including the role of infrastructure development (especially globally) in transportation-related emissions trends. Although not specific to BC, the Report could reference U.S. DOT (2010) on this topic.

Fuels

Under mitigation approaches, there is little discussion of the large-scale conversion to clean, renewable energy (e.g., converting electric power, transportation, heating/cooling and industry completely to electric power and hydrogen, where the electricity for both is derived by wind, water and solar power). A plan describing such a conversion is given in Jacobson and Delucchi (2011) and Delucchi and Jacobson (2011). In addition, there is likely to be more emphasis on biofuels and “low carbon” fuels in the future. Thus, the Report should discuss the implications of increasing use of biofuels, including the changing composition of PM and emissions of BC.

[2] Gasoline direct injection technology is beginning to enter the marketplace and is expected to gain significant market share in some countries in the future. Unless controlled, this technology can have significantly higher PM and black carbon emissions than a “conventional” gasoline fueled vehicle.

Health and Exposure

The Key Message on public health co-benefits (p. 6-1, lines 31 et seq.) refers to "reductions in directly emitted $PM_{2.5}$" as a means to substantially reduce human exposure. This discussion needs to clarify whether this refers to the benefits of reduced exposure to $PM_{2.5}$, reduced exposure to directly emitted $PM_{2.5}$, or reduced exposure to BC. In regions where $PM_{2.5}$ is dominated by secondary aerosol, the statement as written would be misleading. Also, the Report discusses spatial aspects of global warming benefits of BC reductions, but does not acknowledge the spatial aspects of the health benefits from $PM_{2.5}$ reductions.

BC as a share of $PM_{2.5}$ varies by emission source. Absent a more detailed discussion of the differential toxicity of specific components of $PM_{2.5}$, the Report should emphasize that the health benefits cited per ton of reduced BC emissions do not differentiate between BC and other components of $PM_{2.5}$. The Report makes it clear that BC health effects cannot be studied in isolation and that the composition of BC in PM varies greatly, depending upon its source. It is important, however, that this be revisited as additional studies become available. For example, Grahame and Schlesinger (2010) provide numerous references to health studies involving BC and its surrogates.

With respect to health effects in developing countries, the Report should note the challenges associated with comparing health benefit valuation across countries and should include this topic as an area for future research.

Reductions in BC Emissions

Developed countries in general, and the U.S. in particular, already have regulations that have reduced, and will continue to reduce, PM emissions (and, as a result, BC emissions). In discussing benefits from mitigation, what percentage of the BC ($PM_{2.5}$) benefits is due to current, in-place, policies and what percentage is due to optimism for new policies that have not been enacted? The Report should explore the most appropriate way to put this into perspective. As presented, the discussion of the potential benefits from mitigation approaches is confusing. In part, this may be driven by the uncertainties underlying the science, but it may also be due to conflicting "recommendations." For example, the reader is told that moving away from diesel fueled transport methods (e.g., trucks) to rail and shipping would reduce BC emissions. Yet, the Report also says that shipping—particularly in areas close to the Arctic—could lead to BC deposition which could lead to warming. It is not clear which is the lesser of these two sources.

In the presentation of benefits and costs (e.g., Table 6-2), the cumulative benefit (versus cumulative cost) in constant dollars is at least as important as the benefit-to-cost ratio at some point in the distant future. Both need to be presented and discussed, perhaps by plotting the ratio (or annual benefits and annual costs) versus time for the full period of the analysis. There is also a need to define what costs should be included for the different remediation technologies and then identify the elements of these costs that are included in the cost estimates reported.

To be most informative, estimates of BC reductions should be presented along with the costs of these reductions. Also, the authors should consider including a discussion of potential alternative abatement approaches because what we have right now might not be the most cost-effective way to get to reductions. (Additional discussion of cost-effectiveness evaluation is provided in Section 4.6 below.)

4.5.2 Mobile Sources (Chapter 7)

Chapter 7 includes a good overview of mitigation options for mobile sources and it is justifiably diesel-centric. To provide some balance, however, additional discussion of other mobile sources of BC (e.g., gasoline vehicles) is suggested. Also, the Report should more clearly explain the type of engines used in various applications because engine type can greatly impact the BC emissions. For example, 2-stroke engines typically are smaller engines (although locomotive engines are also 2-stroke) and are used for lawn and garden equipment such as handheld string trimmers. In contrast, 4-stroke engines are more widely used for lawnmowers and for larger nonroad equipment such as construction, farm, and industrial (CFI) equipment. Other factors that reduce vehicle emissions should be discussed, including policies that reduce demand for vehicle use and transportation in general (e.g., land use change); increased use of modal substitutions – pedestrian, bike, mass transit as alternatives to personal transport; modal substitutions for freight among truck, rail, waterway (inland, coastal); fuel reformulation and substitution; electrification; engine technology; and efficiency (reduced aerodynamic drag, idle reduction, hybrid vehicles, etc.).

There have been large changes in the economy, which may keep existing vehicles in service longer. Increasing fuel prices may cause a substitution/shift to intermodal freight facilities. It would be good to at least acknowledge these effects and give some insights on how these moderators/confounders would affect costs and projected reductions. Also, cost per unit reduction is assumed to be constant. If the easiest reductions have been accomplished (i.e., low hanging fruit), it is reasonable to expect that per unit marginal costs will increase to attain additional reductions; a fact that requires discussion. In the description of diesel retrofits, it is not clear what is included in the cost estimates presented in the Report. Please consider clarifying the cost estimates presented with respect to the cost of installation (new and retrofit), fuel, new vehicle inspections, regulatory compliance and possibly others. In addition, the Report should discuss the need for maintenance to preserve effectiveness of a retrofit and the associated costs of this maintenance. Filter disposal and handling of potentially hazardous waste from the filter also should be considered.

The Council recommends that a summary table be developed to present cost and expected emission reductions for each technology/policy option. Included in the discussion should be clarification on the impact of DPFs on CO_2 or efficiency and clear definition of passive and active DPFs, catalyzed and uncatalyzed devices. As noted in comments on Chapter 6, the discussion of mobile sources includes mostly catalytic technologies, but the chapter also could explore the option of non-catalytic DPFs in some non-road sectors using higher sulfur fuels. If possible, it would be helpful to include a discussion of the costs for future BC control beyond the current regulations.

In the area of ocean-going vessel emissions, the Report should reference the strong U.S. position statements submitted to the International Maritime Organization’s (IMO) Marine Environment Protection Committee (MEPC), and statements by other governmental bodies internationally (e.g., Norway, Sweden and the United States 2010)

The Report’s discussion of engine standards in Europe (Euro 5 and Euro 6) should clarify that the European Particulate Measurement Programme (PMP) methodology (mentioned on p. 7-14, 15 and Footnote 11) does not include a thermal denuder. The methodology simply calls for use of a volatile particle remover via thermal treatment of the exhaust samples. A thermal denuder connotes conventional usage of carbon scrubbing and this is not the case for PMP. The distinction between particle mass or particle number is subtle, but deterministically important. PMP excludes some organic compounds, but these organics appear roughly in the sub-50 nanometer particle size range so they do not contribute much to PM mass. PMP was explicitly designed to ascertain differences between various kinds of DPFs in the solid particle number emission range where the standard PM mass measurement was unable to distinguish.

Table 7-1 is a nice summary of projected mobile source emissions, but there is a substantial lack of transparency/documentation of the basis of these estimates. Basic supporting information that underlie these estimates should be given in an appendix, including, for example: vehicle age distribution by calendar year, and implied rate of turnover of vehicle fleets; emissions deterioration; fleet mix; changes in vehicle miles traveled (VMT) or other indicators of activity. In the table (and throughout the document), appropriate specification of significant figures is needed to avoid misleading impressions of high precision of estimates.

4.5.3 Stationary Sources (Chapter 8)

Chapter 8 discusses the options for mitigating BC emission from stationary sources. The overarching $PM_{2.5}$ criteria pollutant control program for stationary sources in the U.S. and Europe has focused mainly on secondarily formed particles, such as sulfates and nitrates, rather than direct $PM_{2.5}$ emissions. With respect to emission inventories, nothing in this chapter confirms that there will be substantial domestic or international reductions in the 8 and 14 percent shares, respectively.

The Council identified a number of areas for improvement. In general, the chapter reads like a manual on air pollution control, without being specific enough to BC. The text should concentrate on the sources where meaningful reductions in BC can be found. Specific suggestions for improvement include the following.

- Smaller and older coal combustion units might typically be lower in efficiency than newer units and thus have lower capacity factors (utilization) than newer or larger units. It is not clear that such units “may demonstrate greater cost-effectiveness,” as stated on page 8-7 (lines 17-20); this statement needs further justification either based on citation to relevant reference or perhaps development of a sensitivity analysis in an appendix that supports this statement.

- The Report seems to confuse two types of efficiency metrics. One is combustion efficiency, which typically refers to how close the combustion process comes to complete oxidation of the fuel. The second is boiler efficiency, which has to do with the ratio of thermal energy available for input to another process area (e.g., steam cycle) relative to the thermal energy of the fuel (based on heating value and mass fuel flow rate). These are distinct concepts, and the text (p. 8-8, lines 23-25) likely is referring to combustion efficiency (which would affect emission rates per unit of fuel consumed) rather than boiler efficiency.

- The Report (p. 8-9) suggests that fuel switching usually requires small capital investment. However, fuel switching can include switching among coals that have different sulfur and ash content. This type of fuel switching usually entails substantial capitals costs for replacing pulverizers and possibly enlarging the electrostatic precipitators (ESP) due to differences in coal hardness and fly ash resistivity, respectively. Sulfur content of coal is generally higher than for distillate oil, and even if similar, the heating value of coal per unit of mass is much less, leading to higher SO_2 emissions per unit of energy released.

- The discussion of conversion from coal to gas or wood as an option to reduce CO_2 as well as BC emissions requires clarification. Presumably, the idea is that there will be a reduction in "emissions rates." If the concept is a reduction in emission rate, what kind of rate is implied (e.g., per unit of energy released during combustion)? Furthermore, such a comparison should take into account the fuel cycle emissions. For example, would natural gas obtained from hydraulic fracturing of shale have lower marginal CO_2 emissions impact than all coals?

- The Report states that catalysts are used to enhance the oxidation process, especially to enable efficient particle filtering across transient loads where exhaust temperatures may not be maintained sufficiently high to achieve removal targets. However, similar to the statement previously made and applicable to mobile sources, if diesel systems are performing in stationary or some nonroad conditions (e.g., marine) where the loads are not transient and the exhaust temperatures are high enough, then non-catalytic DPFs can be used with higher sulfur fuels (range of ~300-700 ppm or more).

Other issues are suggested here for additional consideration. Power generation emission control and the tendency for electrification in the developing world deserve more discussion. For power generation from fossil fuel combustion, it would help to quantify/compare uncontrolled versus controlled PM and BC emissions. This information would help set the stage for the international context, where some fossil-fueled power plants lack PM and BC control or are controlled using ineffective technologies such as cyclones or multicyclones. The role of ESPs in controlling BC also needs additional discussion leading to recommendations. The Report should address the efficacy of ESP-based control of very small carbon and non-carbon particles. The use of an amine-based scrubber on a pulverized coal-fired power plant may lead to some decrease in PM emission rate per kWh of electricity generated. Finally, the possibility of carbon capture and sequestration for fossil-fueled power plants should be mentioned.

In the transport sector, the role of plug-in vehicles on electricity demand should be addressed. Thus, even though BC emissions from U.S. power generation have generally decreased, there could be future increases in power demand that might change the trend, particularly from coal-fired plants. Ultimately, electrification that is based on an increasing share of non-fossil power generation would lead to lower BC emissions per kWh available from the grid.

Finally, it would be useful to explain what portion of PM emissions from coke ovens are fugitive emissions. For example, the Report should explain the contributions to total emissions from removing coke from the oven versus emissions from the stack. Insight regarding control measures and their effectiveness depends on some basic process information. Section 12.2 of EPA's Compilation of Air Pollutant Emission Factors (AP-42), would be a useful reference here.

4.5.4 Residential Heating/Cooking and Biomass Burning (Chapters 9 and 10)

Chapters 9 and 10 provide a good overview of the challenges associated with controlling emissions from residential heating and cooking and from open biomass burning. While a full range of options is presented, it should be noted that implementing the fire control options presented in the Report will be challenging in many part of the developing world. In addition, the cookstove discussion would benefit from a more detailed consideration of what might be applicable in which regions of the world. Local cultural barriers, resource availability, and the challenge of maintaining cookstoves in regions that presently rely on three-stone cooking fires make solutions in one area likely inapplicable to others.

Going forward, a more refined region-specific assessment of the opportunities in this area would strengthen this analysis and discussion.

It is unclear whether the strong seasonality of the use of wood-burning appliances was considered in the discussion in chapter 9. For example, it is noted on the first page that U.S. residential wood combustion is responsible for "approximately 3% of the domestic BC inventory." While this is true in aggregate, it is responsible for a much higher percentage of the emissions during the winter season (presumably a value closer to 10 percent) and as a result, may be responsible for a significant fraction of the effects of BC through deposition on snow and ice –covered surfaces.

Regarding mitigation of BC emissions from cookstoves, the discussion of 90-95% reductions in BC emissions per household seems very optimistic. A sense of a more reasonable level of penetration would be helpful. Also, nothing in this chapter confirms that that there will be substantial domestic or international reductions. Reach and effectiveness of voluntary programs has not been established. In sum, the Council had some question about the BC reductions likely to be achieved by cookstove mitigation approaches, and notes the following:

- The BC/OC ratio for cook stove emissions is low, as stated many times in the Report. Thus is it really the relevant outcome?
- Cookstove emissions are significant only in other countries and it is not clear the extent to which U.S. policy can affect this source.
- The ability to provide more efficient cookstoves to potentially millions of people in certain parts of Africa, India and Asia does not seem feasible – at least not without an infrastructure that can support such a program. Cultural barriers, the challenge of repairing broken stoves, and differences in cooking may make it difficult to achieve any significant penetration of improved cooking stoves into developing countries, particularly in rural areas.

Chapter 10 is comprehensive and adequately describes the relatively limited options for reducing BC emissions from open burning of biomass. Table 10-1 lays out the scope of the challenge, and Section 10.6 clearly discusses the challenges in implementing any of these strategies in the developing world. However, clarification of the share of anthropogenic sources of BC *vis a vis* wildfires is needed. Since the natural fire sequence is not what led to the current altered climate state, it does not seem logical to further suppress natural wild fires (or prescribed burns which may be making up for past policies of unnatural suppression). The Report might briefly note that fire and other forest management practices may alter the general uptake and release of gaseous carbon by forests and grasslands – not just the BC or BC and OC taken in isolation.

4.6. Costs and Benefits

4.6.1. The Economic Framework

The Council urges EPA to add a chapter to the Report that summarizes the economic framework and available economic data. The economic framework includes both benefits and costs. The Report should clearly state that production and control of BC and $PM_{2.5}$ are joint products. The economics chapter will build on this foundation, realizing that the control of BC as a share of PM will vary by source and control approach. This recognition is crucial to avoid double-counting of benefits across different policies designed to reduce BC and other PM emissions.

The chapter should start with the endpoints to be valued from reductions in BC emissions, both environmental and human health. The discussion should link to the previous chapters in the Report so that the reader will know that the control of different sources and different control strategies can have different environmental and health impacts. That is, not all PM controlled is equal in terms of the environmental and health improvements. Variation could be due to the physical characteristics of the PM controlled, the location of the PM controlled, etc.

The chapter should then move to the benefits to be measured given the health and environmental endpoints identified. Any empirical value estimates reported should be evaluated in terms of the extent that they match with the desired economic concepts of benefits to be measured. Similar consideration should be given to the definition and reporting of costs. More will be said on the issues of costs (Question 12) and benefits (Question 13) below.

The Report discusses uncertainties related to BC reductions early in the Report, but these discussions do not carry through to the reporting of benefits and costs. To the extent possible, any qualitative insights that can be provided on how the uncertainties affect the measurement of economic benefits and costs would greatly improve the Report.

Reporting benefits and costs in per ton units is a convenient metric, but caution is warranted. These calculations assume linear benefit and cost functions, which may or may not be appropriate, and per-unit benefits and costs may vary by source within an emission category, over time, and spatially (esp. internationally).

Finally, no mention is made of the time dimension of benefits and costs. For example, the up-front cost of diesel particulate filters (DPFs) (including costs of research and development and vehicle purchases as the diesel fleet turns over) are relatively immediate, while environmental benefits are delayed as new trucks are purchased and DPFs come into full use. Although some health benefits will be near-term, others will be associated with premature deaths prevented 20 to 30 or more years in the future. The Report is silent on the need for caution in assuming per ton costs and benefits occur in the same period, and the need to discount future benefits and costs to the present.

As noted previously, it is often unclear whether the benefits discussed in the Report are coming from existing policies or potential policies that could be put in place sometime in the future. Clarification would allow readers to think more systematically about potential costs and benefits of future actions, as well as future benefits that may accrue from existing policies.

Although the Council understands the rationale for not including a cost-benefit analysis in the Report, it would be beneficial to organize the discussions of costs and benefits in the Report in a manner such that an informed reader could use the information provided to think more clearly about the potential ramifications of both the costs and the benefits of future policy actions. The Council urges EPA to do this through the new chapter dedicated to the economic component of the Report and the use of summary tables on benefits and costs in this chapter.

Although the Report falls short on the charge to identify cost-effective approaches and provides an incomplete discussions of benefits, the weight of evidence from the published literature supports a finding that substantial, near-term reductions in BC emissions, in both developed and developing countries, are well-justified by expected human health benefits alone. Thus, the final report should present a compelling case for expanding and accelerating current efforts to reduce BC emissions in both developed (including the U.S.) and developing countries.

4.6.2 Costs of BC Reductions

> *Charge Question 12. Can the Council suggest other reliable sources of information on the costs of reducing BC emissions, particularly for international sources, that should be considered in the Report?*

The Report cites numerous sources of cost information for a variety of remediation technologies that seem to be appropriate. However, the Council has more fundamental concerns about the cost information presented in the Report. A key component of the Congressional charge to EPA was to present "… an identification of the most cost-effective approaches (emphasis added) to reduce black carbon emissions …" The Council does not believe the Report is responsive to this element of the Congressional charge.

Cost-effectiveness is a relative concept. If there is more than one approach to accomplish a reduction in BC from a given source and all approaches accomplish the same reduction in BC, then the cheapest alternative would be the cost-effective approach. The key element is that more than one approach is compared. In addition, each approach should accomplish the same reduction in BC to facilitate the cost comparison. Throughout the Report, starting with the Executive Summary (e.g., p. Ex-5, 3rd & 4th bullets), the term "cost-effectiveness" is used inappropriately. The Report presents a variety of cost numbers associated with a variety of BC mitigation approaches. However, these cost numbers are simply the costs of implementing the discussed remediation approaches, rather than comparative cost-effectiveness of multiple mitigation options.

The Council understands the difficulty in doing true cost-effectiveness analyses for the unique approaches to mitigating BC from different sources. For each BC source there may be one logical remediation approach and only one cost estimate for implementing this remediation approach. With this limited information it is impossible to evaluate the cost-effectiveness of remediating BC from this source or the cost effectiveness of implementing a remediation approach. An alternative cost-effectiveness analysis would be to compare the costs of remediating BC from different sources. Such an analysis would allow EPA to identify cost-effective priorities for BC remediation by major emission category and is likely the best approach given the available data. The limitation to this approach is that the different mitigation options do not accomplish the same reductions in BC. Still, if costs are expressed in per-ton units of BC remediated, then comparisons across sources are possible as long as it is reasonable to assume that costs are linear over the ranges (and remediation approaches) considered.

The Council supports EPA's use of existing cost data, but caution is needed. For each remediation approach, EPA needs to identify the categories of cost that are appropriate, e.g., capital, operating and maintenance, replacement, regulatory and waste disposal. Based on this framework, the Report should note whether the available cost estimates include all elements EPA has identified and any qualitative insights EPA can provide on the reliability of each number.

Cost data are currently distributed throughout the Report. The Council recommends that cost information on the remediation approaches be organized in an economics chapter, and that a table be developed to summarize remediation approaches by BC source; a qualitative assessment of the remediation approach; the cost per ton of remediation for each approach, if available; and a qualitative assessment of the reliability of the cost numbers. When possible, the table should indicate whether the cost estimates reported are marginal or average costs and the range of BC remediation relevant to each cost estimate. Costs should be reported in current year dollars (e.g., 2010).

The Council realizes that the summary cost table will have blank cells, but conveying this lack of knowledge is useful and supports the conclusion that research on costs should be added to Chapter 12.

Clearly, not all cost estimates are of the same quality. However, with these data spread throughout the Report and no systematic discussion of their quality, the implicit message is that all estimates are of the same quality. Assembling the cost discussion in one chapter with a summary table that includes qualitative assessments will help the reader understand where there is better cost data and weaker cost data.

Most cost data are based on U.S. information. At the end of the cost portion of the economics chapter, the Council urges EPA to include a section that discusses what is known about cost data for international BC sources. The international discussion should not be interspersed throughout the economics chapter.

It should also be noted that there is strong evidence that actual costs tend to be lower than the *ex ante* estimates, indicating that the preliminary cost estimates tend to be higher than they actually turn out to be. Further, the actual costs of controls are expected to be substantially lower in many developing countries. In part this is due to the lower labor costs in these countries compared to those in the developed world and in part due to the research and development that has already been conducted and does not need to repeated, e.g., later adopters have lower costs than the original adopters.

4.6.3. Benefits of BC Reductions

> *Charge Question 13. Does the draft Report appropriately characterize the range and magnitude of potential benefits for both climate and public healthy that could result from reductions in BC emissions?*

As discussed in the response to Charge Question 6 (Section 4.2), the Council notes that the Report's characterization of the potential health benefits from BC emissions reductions was too cautious. Although many of the health papers cited focus on $PM_{2.5}$ and not just on BC emissions, it is important to note that on a mass basis, BC is the largest component of PM emissions. There is overwhelming evidence that reductions in BC emissions will have widespread health benefits. Given the potential magnitude of these benefits, greater emphasis should be given to this result. To this end, it is critical for the Report to have a more detailed and thorough review of the existing health literature (along with a discussion of any important issues surrounding uncertainty) in Chapter 3.

The Report should emphasize the joint benefits that will accrue from the reduction of BC emissions. By controlling BC emissions, there are both health benefits and climate benefits. Furthermore, because of the joint production of BC and other particulate matter, the control of BC emissions also will help to control releases of other fine particulate matter – which may have additional benefits

Uncertainties in potential benefits are discussed in the earlier chapters of the Report, but those uncertainties were not carried forward to the later chapters. The Council strongly recommends that a Summary Table be constructed that lists the potential health and environmental endpoints from BC mitigation, the regional impact of their effects (local, regional, and/or global), and the monetary benefits, where possible, as well as the associated uncertainties surrounding the magnitude of these benefits. The Report should clearly define how the monetary benefits are measured (value of a statistical life, avoided medical costs, a stated-preference study, etc.) and the incremental change in BC, or more appropriately PM, for which the monetary values apply.

As with costs (see response to Question 12), throughout the Report there is an implicit assumption that benefits are a linear function of BC mitigation. The Council agrees that for industrialized countries, in particular, the U.S., Canada, and Western Europe, the assumption of linear benefits (constant marginal costs/benefits) may be reasonable. For developing countries, however, this assumption is more problematic and deserves careful consideration.

Benefits associated with BC emissions reductions, particularly those in developing countries, will depend upon the feasibility of implementing effective mitigation strategies. As noted in Section 4.5 above, The Report would benefit from a more thorough investigation of the feasibility of the mitigation strategies to better inform the reader about the likely realization of the benefits.

It is valuable for the Report to include a specific internal EPA study (Anenberg et al., in preparation) on the benefits of BC emission reductions for human health. However, it is a little difficult to evaluate the evidence and compare it with the other cited studies without more detail, especially since this study has not yet been published. At a minimum, the text should mention which global atmospheric model was used, and the specific concentration-response function should be listed, since Krewski et al. (2009) report numerous values. It is also reasonable to expect that the core reason why the mortality impact per unit emission of BC is higher in South Asia than East Asia is population density, probably less so than a smaller impact on concentrations.

A great deal of attention is placed on the differential effects that BC emissions may have both seasonally and spatially, but the corresponding discussion is not developed in the discussion of benefits in the Report. These differences should be made more transparent.

The Report uses a benefit transfer approach to benefit estimation, using benefit measures that are provided in the literature. Thus, it is critical to specify exactly what benefits are being measured and discussed, and any adjustment done to calibrate transfer estimates to current application. It is also important to note that measurements that are typically used in industrialized countries (e.g. value of a statistical life) may make less sense when used in developing countries. Problems of measurement may be further exacerbated when potential benefits come in the future and must be discounted to the present.

4.7. Metrics for BC Climate Effects

Charge Question 14. Does the draft report accurately describe the range and limitations of metrics available to quantify and/or communicate the climate effects of BC, to compare BC with long-lived greenhouse gases such as CO_2, and to compare among BC mitigation alternatives?

Chapter 11 gives a good overview of metrics and related issues. It contains important information but the discussions needs to be more linked to possible climate targets or purposes of BC mitigation strategies. The adequacy of metrics depends on the overall purpose, which is not clearly stated beyond a certain focus on rate and short term warming. As discussed below, an evaluation of adequacy of metrics must be put into context (see Plattner et al. 2009, section 4.1.1). In this regard, it may be useful to provide the specific mandate from Congress, along with the strategy EPA is taking to respond to the charge. The Council suggests that the material in Chapter 11 be divided into two parts; one part discussing concepts and perspectives (to precede the current Chapter 2) and one later in the Report on applications of metrics in the context of mitigation and policy-making. Further, the Council recommends improvements and additions to the graphics used in the chapter.

Dependence on Climate Goals

The Report should state clearly for policymakers that the utility of particular metrics will depend upon the goals of climate policy. Even though not intended to recommend a specific policy or set of policies, the Report should further discuss possible climate policy goals (e.g., climate stabilization, reducing short-term warming, reducing the rate of warming), and how the various goals would impact the choice of metrics and mitigation strategies.

Within this context, the Report would also benefit from a more focused and structured discussion of the role BC mitigation might play given various types of climate targets; i.e. a long term stabilization target, a short-term target, or a rate-of-change target. In the introduction it is stated that, "*BC offers a promising mitigation opportunity to address short-term effects and slow the rate of climate change.*" The Report might emphasize that this overall target differs from the long term stabilization target in the statements from Cancun and Copenhagen. If short-term climate effects and slowing the rate is the likely motivation for BC controls, this should be followed up throughout the Report. This focus will have impacts on the use of metrics and potentially also on the identification of cost-effective multi-component mitigation strategies.

As shown in several papers (Manne and Richels, 2001; Shine et al., 2007; Manning and Raisinger, 2011), the global warming potential (GWP) concept is not suited for a policy with stabilization as the overall goal. The global temperature change potential, GTP(t), concept presented by Shine et al. (2007) is one alternative in this context; see discussion below.

The Report is unclear about whether metrics are sought to choose among various BC reduction alternatives, or across components. Attempts to assess the effectiveness of mitigation options for multiple categories of climate forcers (i.e., the multi-component approach or "basket approach") is problematic if we try to "force" components with very different lifetimes into the same basket with one static metric like GWP100. There are severe difficulties related to using one single metric and time horizon for comparing components with very different lifetimes. Better alternatives include a multi-basket approach (e.g., Rypdal et al. 2005; Daniel et al., 2011), or a single basket with a metric that is a function of time (e.g., Manne & Richels 2001) or the GTP(t) from Shine et al. 2007).

Further, it is difficult to force BC into the current climate policy framework (i.e., the Kyoto Protocol's multi-component basket) if we are concerned about more than long-term change. However, if we are concerned about more than the long-term temperature, then an additional target could be formulated (e.g., a short-term target or rate-of-change target). As stated by Berntsen et al. (2010):

> Our discussion assumes a climate policy with one long-term target. It has been suggested that an additional short-term (Fuglestvedt et al. 2000; Rypdal et al. 2005; Jackson 2009) or mid-term target (O'Neill et al. 2010) can be introduced to the climate policy as an interim goal leading toward the long-term target. The motivation to set up such an interim target may also be as a means to avoid crossing the tipping elements (Lenton et al. 2008) or to curb environmental side-effects (e.g. adverse human impacts of BC emissions). When such an additional target is introduced, a possibility to develop strategies and policies that could in a consistent manner employ different timescales for metric calculations opens up.

The Report would also benefit from a discussion of the scale (i.e., national, regional, and/or global) of possible BC policies.

Scope of metrics

The importance of regionality and spatial variations is stressed, but the Report should distinguish more clearly between the regionality of the *driver* (i.e., emissions) and the *response.* For BC, the location of emissions is important to the magnitude and pattern of response. Note however, that the regional patterns of the radiative forcing (RF) – which is the main endpoint used in the Report– are different than the patterns of the temperature response. The chapter could also be more explicit about the importance of time horizon with respect to rate of change and short- versus long-term effects.

Obviously, one purpose of metrics is to put effects of various climate forcers on a common scale; i.e. to compare effects of BC reductions to effects of reducing other components. This use of metrics is consistent with the Congressional charge. However, the chapter also discusses the use of metrics to compare across sources (which are different due to different location of emissions). If direct comparison with CO_2 is not the objective, it would be useful to group the components in different baskets according to their lifetimes/adjustment times (Fuglestvedt et al. 2000; Rypdal et al. 2005; Jackson 2009; Daniel et al. 2011). To summarize, it is sometimes unclear whether the Report is searching for metrics to compare alternative for reducing BC or to compare BC reductions with CO_2 reductions.

Application of Metrics

The differences between BC and CO_2 are stressed throughout the Report, but the *implications* of these differences could be given more attention. A figure showing the RF and dT responses to pulses as well as sustained constant emissions of BC and CO_2 would illustrate the differences in temporal behavior of these components (see below).

The presentation of RF effects of BC (and other components) also needs a clear distinction between a *backward* looking perspective (as used in Figs. 2-7, 2-8, 2-9, 2-11, 2-13 and 2-14) and a *forward* looking perspective (as in Fig. 2-16 from Unger et al., 2010). Figure 2-7 in the Report shows the current RF relative to pre-industrial times. These RF numbers in Figure 2-7, which represent the instantaneous values for year 2005, could be placed in context using a graphic that illustrates these levels relative to pre-industrial times with development in RF over time; e.g. figure 3 in Fuglestvedt et al. (2010). See also discussion in IPCC AR4, sections 2.9.2-2.9.5.

The Report should explain the differences in temporal behavior of the various components; i.e., that a perturbation of CO_2 is very long-lived, while forcings from ozone (O_3), black carbon (BC) and sulphate (SO_4) die out quickly after the emissions stop. Thus, one should keep in mind the very different behavior the agents show after the chosen year due to the very different lifetimes; Figure 2-7 in the Report does not say anything about the future role of the various RF agents.

The different purposes of these backward and forward looking perspectives (for attribution and understanding vs. policy-making, respectively) should be explained. The Report would benefit from more emphasis on forward looking perspectives since the motivation is mitigation and policy-making; e.g., as in Figure 6.4, but by component and/or by sector. (In Figure 6.4, it is not clear how big the contribution from BC is; only the combined effect of methane and BC. It would also be useful to know the extent of the cuts (% or mass) in BC and methane emissions that are assumed in the calculations behind Figure 6.4.).

RF for 20 and 100 years after emission - for sustained constant emissions – is used as a metric in Figure 2-16. In order to avoid confusion, it should be explained that this is approximately the same as using integrated RF for one-year pulse emissions; which is in line with using Absolute Global Warming Potential (AGWP) for evaluation of emissions.

Various metrics are discussed in Chapter 11, but the Report could apply some of these metrics to gain insight to the climate impacts of BC and BC reductions; i.e. E_i x $M(H)_i$; and implications of this. See, for example, Figure 7 from Fuglestvedt et al. (2010). Alternatively, a figure like Figure 2.22 from IPCC AR4 WG1 (or an update) would be useful. To illustrate the magnitudes of the contributions from BC compared to CO_2 and methane, e.g. for the U.S., one could multiply the U.S. emissions by (various) metrics for these gases.

Metrics can be used to illustrate the very different temporal behavior of BC and CO_2. The example figure below (Figure 8) shows - in a generic way - the development in temperature effect in response to emissions of carbon dioxide (CO_2), methane (CH_4) and BC. The effect of BC is strong but short-lived, while the effect of CO_2 is more long-lived. The effects of BC mitigation on short-term warming and rate of warming (assuming ranges for the magnitudes of the various effects of BC) could also be illustrated by a figure.

The Report could refer to figure 4 in the recent UNEP assessment (UNEP and WMO 2011) in order to show the time profile for responses in short-lived vs. long-lived components. As stated earlier, the text should make it clear that the reductions in warming in those calculations also include responses to CH_4 reductions. The EPA could also consider making a similar figure for BC-only reductions. For sustained emissions, the effect of BC would be larger at an approximately stable level since new emissions are added to the atmosphere each year. The effect of CO_2, on the other hand, would accumulate over time. Such illustrations would help to convey the very different behavior of these two components. Metrics also can be used to illustrate the propagation of uncertainties in emission estimates (see Figure 9 below).

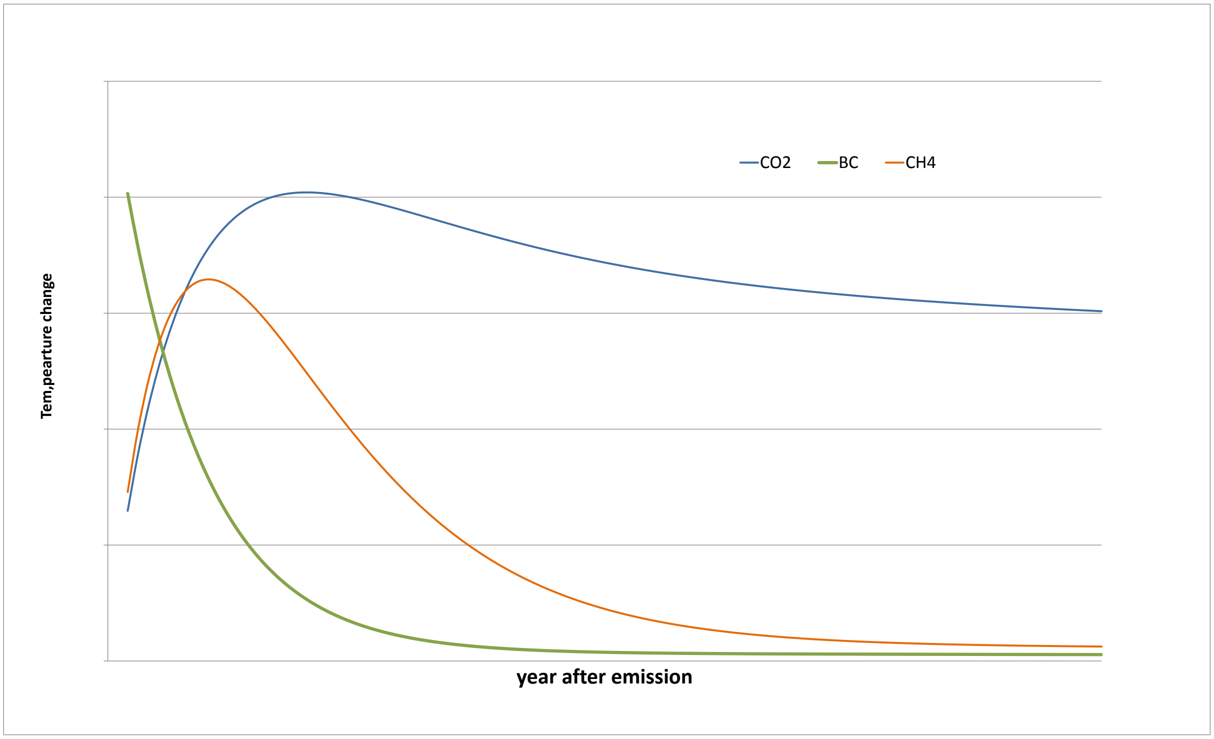

Figure 8. Generic illustration of development in temperature in response to emissions of carbon dioxide (CO_2), methane (CH_4) and BC.

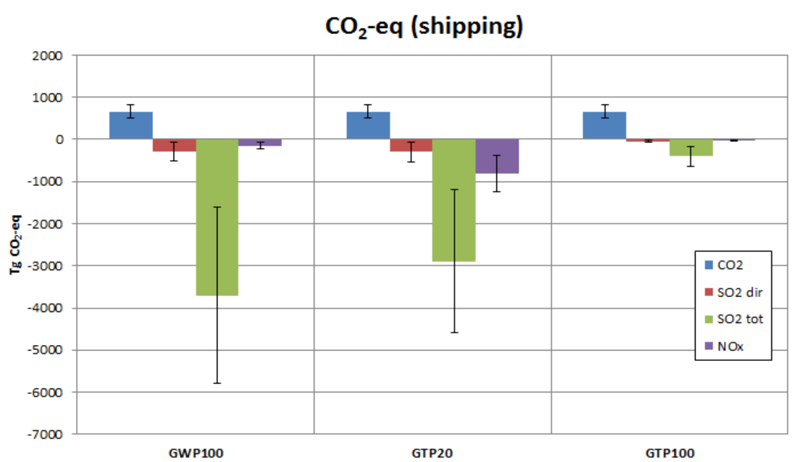

Figure 9. An example of the use of metrics to convey uncertainty, using BC emissions from shipping.

As discussed in Chapter 11, there is currently no single metric (e.g., GWP) that is widely accepted by the science and research community for comparison of climate impacts of different components. However, it is important to differentiate between various applications of metrics: (1) policy targets and international agreements, and (2) assessment and illustration of effects. Obviously, it is much more difficult to agree upon a metric for the first application, while for assessments and illustration of effects, the various metrics can provide insight to the nature of the different contributions from components, such as BC, CO_2 and methane.

In Chapter 2 the RF numbers for the direct effects and albedo effects are presented on graphs. It could be noted that the efficacies of these mechanisms are probably very different.

Possible Metrics

In the Report, the OC/BC ratio is presented as a metric. The Council recognizes that this ratio is a useful indicator if the BrC content of OC is also considered. However, the Council recommends that the OC/BC ratio not be referred to as a metric since this is not based on any climate response (such as RF or dT). The Report discusses problems related to metrics for short-lived components and presents two new alternatives, STRE and SFP**,** and the Council suggests a third:

- ***Surface Temperature Response per unit continuous emission*** (STRE) from Jacobson (2010): This metric is similar to the GTP for sustained emissions (GTPs) presented by Shine et al. (2005). The implicit assumption on sustained emissions (i.e., future behavior and emissions) should be kept in mind for applications in policymaking. Pulse-based metrics can be used for annual emissions and may also be used as building blocks for cases with sustained emissions or for scenarios.

- The ***Specific Forcing Pulse*** (SFP) from Bond et al. (2011) is similar to the Absolute Global Warming Potential (AGWP), with the important difference that selected regions for RF response are chosen rather than global mean RF. The SFP metric uses a different unit (GJ/g) which may seem confusing, so it is quite important that this metric be well explained. It is also worth noting that the regional patterns in RF does not indicate regional pattern in temperature response.

- The **GTP concept** also could be discussed with time horizon as function of proximity to the target year, as suggested by Shine et al. (2007). Figure 5 in Shine et al. (2007) shows the GTP for BC for various scenarios, target years and climate sensitivities. While the GWP value remains constant over time, the GTP values are low in the beginning but increases towards the target year. In other words, the contribution from BC to warming in the target year – *relative to* CO_2 – increases over time. This says nothing about the total absolute reduction needed to stay below the temperature ceiling. See Berntsen et al. 2010, for a discussion of reductions in BC vs. CO_2 for a situation with a temperature ceiling. This metric could be used to show how the value of BC reduction increases as the target year is approached.

As a general comment, the Council recommends that Table 11-1 indicate how transparent the metric formulations are; i.e., simple analytical formulation vs. a complex numerical model.

Additional Relevant Literature

Berntsen et al. (2010) discuss whether a mitigation strategy directed towards BC may hamper CO2 abatement, and Rypdal et al. (2005) and Jackson (2009) discuss how short-lived components can be included in climate policies. Additional papers on the choice and application of metrics include Tanaka et al. (2010) and Manning and Resinger (2011). Studies that could be given more emphasis include Rypdal et al. (2009), which gives GWP and GTP values for various regions of emissions, and Shine et al. (2007), which presents the GTP(t) concept and obtains results (with a physical and transparent metric) that are similar to the results from Manne and Richels (2001), who use an economic model framework.

4.8. Research Priorities

Charge Question 15. Does the draft report appropriately identify the highest research needs regarding BC?

Overall, Chapter 12 provides a succinct summary of most of the key conclusions and research needs outlined in the Report. However, it is lacking in several areas outlined below. In addition, it is written in a technocratic style and would be improved by careful editing and improved formatting and structure which would make it more accessible and interesting to a non-expert.

Conclusions

The UNEP report (UNEP and WMO 2011) illustrates how near-term measures such as BC reduction can complement CO_2 control measures in constraining the global temperature increase to within the critical 2 °C (e.g., Figure 10 below). The conclusions in the EPA report however are cautious. In particular, the conclusions stop short of summarizing the benefits of specific mitigation options. The UNEP report identifies measures that improve climate and air quality and have a large emission reduction potential. It would be useful if the EPA report took a similar approach and identified BC mitigation technologies/methodologies that appear feasible and cost- effective. Commenting on whether they are the same or different from those in the UNEP report would be instructive. It would be particularly useful to rank mitigation options in some way that took account of their feasibility, cost, health and climate benefits. This would facilitate the identification of useful future mitigation policies, including those that are "win-win" because they produce both health and climate benefits.

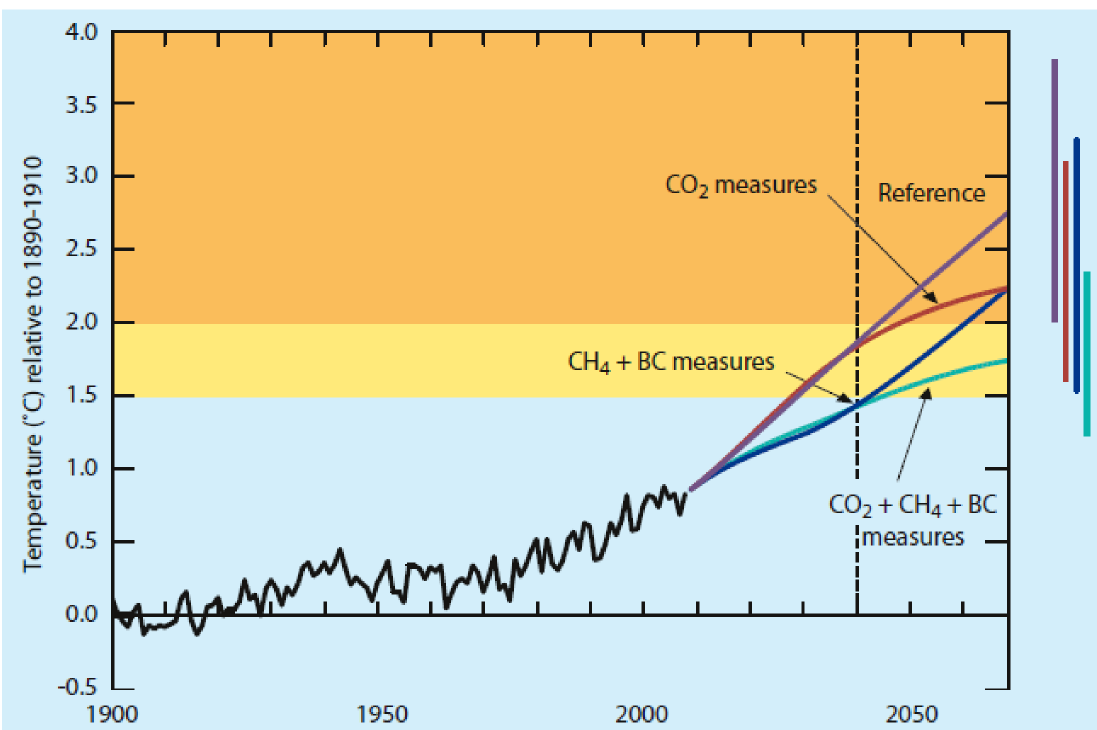

Figure 10. Observed deviation of temperature to 2009 and projections under various scenarios. (Figure 3 from UNEP and WMO 2011).

Without prescribing specific BC policies, the Report should develop recommendations for (a) short-term strategies (such as incentives for early scrappage of high black carbon polluting vehicles or mandatory retrofit of high polluting on and off road vehicles with particulate filters), (b) longer term strategies (such as a shift to zero emitting vehicles such as battery electric cars or hydrogen fuel cell buses), and (c) recommendations for rapidly industrializing countries (such as more rapid introduction of tight new on and off road vehicle standards that would fully reflect today's state of the art black carbon pollution controls), and discuss how selection of metrics and mitigation approaches would differ for the 3 objectives.

Providing research recommendations in the Report is valuable. However, it is also important to provide conclusions about BC mitigation strategies that can slow the rate of climate change and provide benefits for public health. Some mitigation strategies provide such clear benefits that further research is not needed to justify action. Identification of such strategies would be valuable.

Research Recommendations

The Report suggests that priority be given to research in seven areas: standardized measurements of BC, aerosol microphysical and atmospheric processes, emissions inventories, the role of BrC, linking regional sources and impacts, BC climate metrics, and understanding uncertainties. Although the research recommendations touch on many important topics, but they are too vague in places. In addition, they should be put in priority order, not in the order they appear in the Report. Clarity on what should be done first and what can wait is needed. What do we need to know to help EPA determine regulatory priorities? More information on the scale of the effort should be included – should it be domestic? Regional? International? Specific suggestions for improvement include the following:

- **Basic Microphysical and Atmospheric Processes** (currently Topic #2). To better justify the need for research in this area, the Council recommends that additional discussion be added on this topic: "Absorbing aerosols such as BC influence absorption within clouds, the temperature profile of the atmosphere and cloud cover in ways which affect climate yet are not currently well understood. Research on the impact of BC on cloud type, duration, location, extent and longevity as well as the influence of these cloud effects on radiative forcing and precipitation is needed. Few global models are now able to resolve the cloud micro-physics which is of importance in determining these effects. Direct radiative forcing from BC is clearly positive and results in warming. However, early results indicate BC emissions lead to a net positive cloud absorption effect but both positive and negative semi-direct and negative indirect effects. The net result may be negative enough to offset some of the warming due to the direct effects of BC. The net effect of BC on cloud absorption, semi-direct and indirect cloud feedbacks depends on many factors, among them aerosol hygroscopicity, absorptivity, and number concentration relative to background particles. More research on these effects is needed to better quantify the effect of BC on climate." In addition, the title of this topic should be improved by removing from the phrase "to facilitate improvements in modeling and monitoring of BC".

- **BC Deposition on Snow/Ice**. The Council recommends the addition of a research topic on the effect of BC deposition on the melting of snow and ice. This is of particular relevance in areas where BC deposition may affect snow pack that influences the availability of water resources for downstream populations (e.g., California, Himalayas and Tibetan Plateau, Andes, high African mountains) as well as in the Arctic where BC deposition may be increasing the rate of melting of sea ice and thawing of tundra.

- **Mitigation Strategies**. Of key importance is research on which BC mitigation strategies are most cost-effective and beneficial for public health and climate. This is buried in the research recommendations #5 and needs to be a topic of its own. Research needs in this area include:

    - more information on costs and benefits of mitigation by sector;
    - R&D on improved mitigation strategies for some sectors;
    - a way to compare numbers across sectors;
    - information on the toxicity of BC – specific impacts on health versus those of other particulates; and
    - research on the climate impacts of BC reaching specific climate sensitive regions.

- **Climate/Health Metrics** (Currently Topic #6). It would be useful to have a metric which combined the climate and health impacts of BC into a single metric as mentioned in this section. However, such a metric would need to be very transparent so that assumptions and values are apparent. This climate/health metric could then be used to compare mitigation strategies across sectors and regions. Research into such a metric would be valuable and could facilitate national, regional and global mitigation strategies for BC. When selecting a metric, it is critical first to define a goal (e.g., long-term climate stabilization or short term/rate of warming or integration of health and climate effects) then choose a metric. Second, a decision is needed on the scope of the options to be compared. Will the metric be used to compare across all emission sources? Across components – all or separated into groups? Single basket of all warming agents or multiple baskets for different types of agents or comparison between different emission sources of the same agent? As noted previously, the Report should clarify whether metrics are sought to choose among various BC reduction alternatives or across components with positive radiative forcing (i.e., CO2, BC, CH4, etc.).

- **Benefits and Costs of BC Mitigation.** Research needs specific to the economic analysis include: cross-countries study of valuation of the range of relevant impacts, study of the difference (if any) in willingness to pay to reduce impacts that are explicitly linked to climate change (i.e., the cause of the impact may matter), and valuation of reducing the risk of extreme outcomes.

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APPENDIX A: Charge to the Council

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Office of Air and Radiation

March 23, 2011

MEMORANDUM

SUBJECT: Review of the draft *Report to Congress on Black Carbon*

FROM: Steve Page, Director
Office of Air Quality Planning and Standards
Office of Air and Radiation

TO: Vanessa Vu, Director
Science Advisory Board Staff Office

This memorandum provides background information and specific charge questions to the Black Carbon Review Panel of the Advisory Council on Clean Air Compliance Analysis in its review of a draft report on black carbon prepared by EPA's Office of Air and Radiation (OAR) and Office of Research and Development (ORD). This report was developed at the request of the United States Congress, as outlined in *H.R. 2996. Department of the Interior, Environment, and Related Agencies Appropriations Act, 2010.* The draft report summarizes available scientific information regarding the impacts of black carbon on climate and public health, and evaluates the effectiveness of available mitigation approaches and technologies for reducing black carbon emissions. This document will be the focus of a review by the Black Carbon Review Panel (Panel) on April 18-19, 2011

Background

The attached draft document, *Report to Congress on Black Carbon. External Peer Review Draft* (Report), serves primarily as a review and synthesis of available scientific and technical information on black carbon. This information includes published studies, emissions inventories, and observational data records. In developing the Report, EPA has focused on addressing key elements of the congressional charge, which stated that:

"Not later than 18 months after the date of enactment of this Act, the Administrator, in consultation with other Federal agencies, shall carry out and submit to Congress the results of a study on domestic and international black carbon emissions that shall include

- *an inventory of the major sources of black carbon,*
- *an assessment of the impacts of black carbon on global and regional climate,*

- *an assessment of potential metrics and approaches for quantifying the climatic effects of black carbon emissions (including its radiative forcing and warming effects) and comparing those effects to the effects of carbon dioxide and other greenhouse gases,*
- *an identification of the most cost-effective approaches to reduce black carbon emissions, and*
- *an analysis of the climatic effects and other environmental and public health benefits of those approaches."*

To address these requirements, EPA has developed a Report that covers the following topics:

1. Definitions of black carbon, and mechanisms by which it affects climate
2. Net effect of black carbon on global and regional temperature change, in terms of both magnitude and time scale
3. Effects of black carbon on snow and ice; precipitation; and surface dimming
4. Contribution of black carbon to human health impacts associated with exposure to fine particles, and other, non-climate environmental impacts
5. Extent of observational data record for black carbon based on monitoring networks, ice cores, and other observational research
6. Current U.S. and international emissions of black carbon, key emitting sectors, and projected changes in future emissions globally
7. Technologies and approaches available to reduce emissions from key sectors, and costs
8. Potential for black carbon emissions reductions to benefit climate and public health

The Report is organized into twelve chapters and six technical appendices that address these topics. The Report focuses on synthesizing available scientific information about black carbon from peer-reviewed studies and other technical assessments, describing current and future emissions estimates, and summarizing information on available mitigation technologies and approaches, including their costs and relative effectiveness. This Report also describes remaining uncertainties and identifies research and technical information needed to fill gaps in the current body of scientific evidence.

Document Availability

The draft Report is being made available to the Panel in the form of the attached electronic file, which we request that you forward to members of the Panel. Printed copies of this document are being sent today, March 23, 2011, to members of the Panel via UPS.

Specific Charge in Reviewing the draft *Report to Congress on Black Carbon*

We ask the Panel to focus on the charge questions below in their review of the draft Report, but we would appreciate comments on any other topics as well.

<u>General Questions for All Chapters</u>

1 In the Panel's view, does the draft Report accurately interpret and clearly communicate the findings of the current scientific and technical literature, including important uncertainties, pertaining to black carbon (BC)? Based on this literature, what are the

Panel's views on the preliminary conclusions as summarized in the Executive Summary and in the key messages for each chapter?

2. Is the Panel aware of any additional, policy-relevant studies that should be included in the draft Report to inform the preliminary conclusions? Are there specific studies that should be given more or less emphasis?

<u>Additional Questions for Specific Chapters</u>

Chapter 2: Black Carbon Effects on Climate

3. Does the draft Report accurately identify and characterize light-absorbing carbonaceous particles, including BC and brown carbon?
4. Does the draft Report adequately explain and appropriately characterize the differences between BC and long-lived greenhouse gases such as CO_2?
5. Does the draft Report appropriately characterize the mechanisms by which BC affects climate and the full range of climate effects of BC (including best available estimates of the magnitude of those effects)?

Chapter 3. Black Carbon Effects on Public Health and the Environment

6. Does the draft Report accurately summarize and interpret the body of scientific evidence relating to the potential public health effects of BC?
7. Does the draft Report accurately summarize and interpret the body of scientific evidence with regard to potential non-climate environmental (welfare) effects of BC?

Chapter 4: Emissions of Black Carbon

8. Does the draft Report appropriately characterize available information on historical, current and future emissions of BC and related compounds in the United States and globally, and present this information clearly?
9. Does the draft Report accurately summarize and interpret currently available information regarding the transport of BC emissions downwind of sources and the relationship between the location of emissions sources and the geographic region of climate and non-climate impacts?

Chapter 5 Observational Data for Black Carbon

10. Does the draft Report appropriately characterize and interpret the information on BC that is available from the observational record?

Chapters 6-10: Mitigation Approaches to Reduce Black Carbon Emissions

11. Does the draft Report accurately reflect and clearly communicate information on the available technologies, control strategies, and costs of reducing BC emissions in various sectors? Are there additional control technologies or mitigation strategies for specific sources or sectors that have significant potential to reduce U.S. or global BC emissions that should be included in the Report?

12. Can the Panel suggest other reliable sources of information on the costs of reducing BC emissions, particularly for international sources, that should be considered in the Report?
13. Does the draft Report appropriately characterize the range and magnitude of potential benefits for both climate and public health that could result from reductions in BC emissions?

Chapter 11 Metrics for Comparing Black Carbon Impacts to Impacts of Other Climate Forcers

14. Does the draft Report accurately describe the range and limitations of metrics available to quantify and/or communicate the climate effects of BC, to compare BC with long-lived greenhouse gases such as CO_2, and to compare among BC mitigation alternatives?

Chapter 12. Conclusions and Research Recommendations

15. Does the draft Report appropriately identify the highest priority research needs regarding BC?

Technical Appendices

16. Do the technical appendices to the draft Report contain any information that should be included in the main body of the Report?

APPENDIX B: ACRONYMS

BC	Black carbon
BrC	Brown carbon
CSN	Chemical speciation network
DPF	Diesel particulate filter
EC	Elemental carbon
ESP	Electrostatic precipitator
GHG	Greenhouse gases
IMPROVE	Interagency Monitoring of Protected Visual Environments
NAAQS	National Ambient Air Quality Standards
OC	Organic carbon
PM	Particulate matter
$PM_{2.5}$	Particulate matter less than 2.5 micrometers in diameter
PM_{10}	Particulate matter less than 10 micrometers in diameter
RF	Radiative forcing
TOT	Thermal/optical transmittance
ULSD	Ultra-low sulfur diesel fuel
UNEP	United Nations Environment Programme
UV	Ultra-violet light
VSL	Value of a Statistical Life